THE PETROLOGY OF THE STEVENS PASS-NASON RIDGE AREA, WASHINGTON

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THE PETROLOGY OF THE STEVENS PASS-NASON RIDGE AREA, WASHINGTON

INTRODUCTION

Location and Accessibility

The Stevens Pass-Nason Ridge area lies on the summit of the Cascade Range, approximately half way between the Puget Sound lowland on the west and the Columbia Plateau on the east (cf., Fig. 1). The center of this area is approximately 60 miles east of Seattle. This area is traversed by U.S. Highway 2, the northernmost route of travel across the Cascade Range of Washington. Plate A is a topographic map of this area.

Most of the area thus far mapped lies east of the Cascade Crest and occupies portions of two United States Geological Survey topographic quadrangles—the Skykomish and the Chiwaukum (17). The western boundary of the area studied

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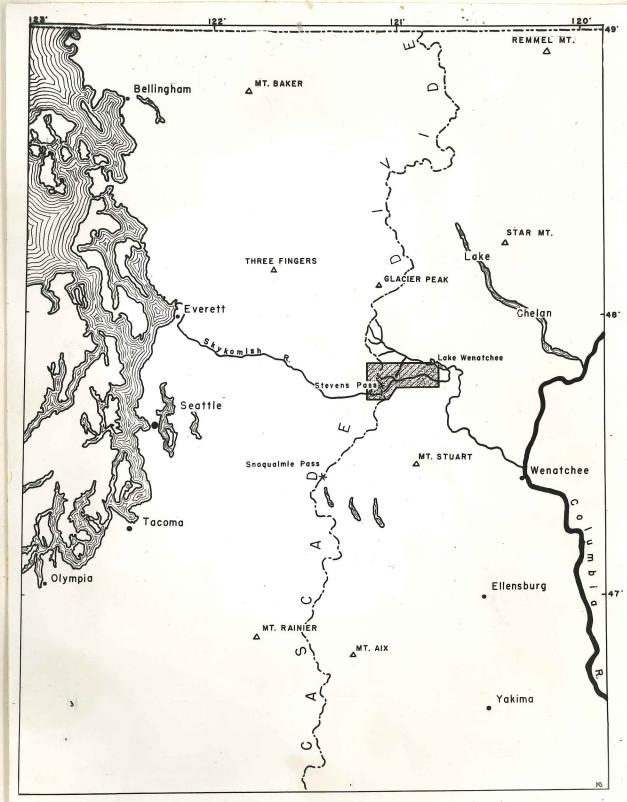


Figure I.—Index map of the northern Cascades showing the location of the Stevens Pass—Nason Ridge Area

passes through Scenic, the highest inhabited place in the Skykomish valley, which is four miles west of Stevens Pass. The eastern boundary is near Lake Wenatchee, approximately 15 miles east of the Crest.

Apart from U.S. Highway 2 the only other roads are an often impassable Bonneville Power Administration maintenance road along Mill and Tunnel Creeks, and a logging road up the Little Wenatchee River. The Great Northern Railway's famous Cascade Tunnel lies beneath Stevens Pass. The Cascade Crest Trail follows the divide in this area. Other trails are few and usually poorly maintained.

Topography and Drainage

The entire area is mountainous and has considerable relief (Plates I, II, and III). Near Stevens Pass there is no predominant trend to the ridges. Peaks and ridges in this vicinity rise to a maximum elevation of about 6000 feet, with a maximum relief of about 3000 feet. East of Stevens Pass the topographic units assume an east-west trend, with maximum elevations exceeding 7500 feet, and a maximum relief approaching 6000 feet. Glacial cirques, often occupied by small lakes, are common, and all the major valleys are glacial troughs.

The two major streams east of the divide are Nason Creek and the Little Wenatchee River. All the eastward

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> Stevens Pass and the avalanche-swept south slope of Skyline Peak, as seen from the main peak of Mt. Fernow. Peaks of the Index and Monte Cristo areas form the skyline.

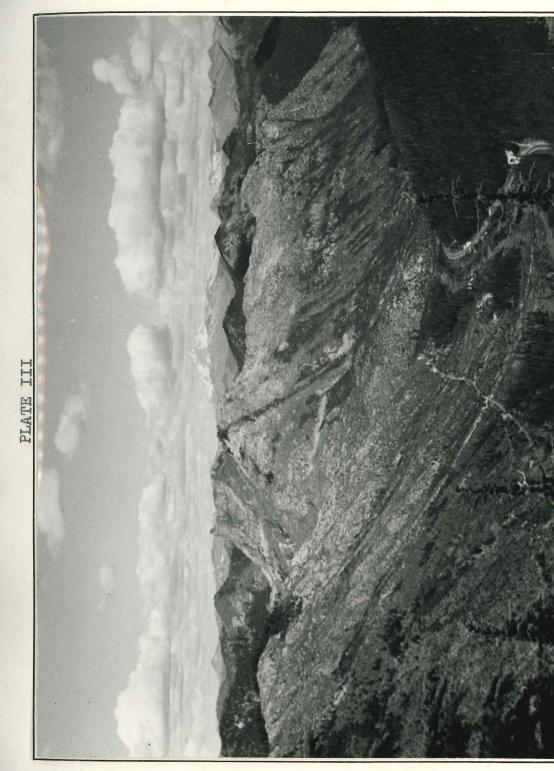
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The two major streams east of the divide are Mason

PLATE II

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Granitic mountains near Stevens Pass. Lichtenberg Mt. lies at extreme right. Part of Skyline Mt. is in the foreground. The horn of Sloan Peak (7,790 feet) lies in the middle distance. View is northwest from the main peak of Mt. Fernow.



The bare granitic slopes of Lichtenberg Mt. occupy the center of the picture. The Cascade Crest takes a serpentine course to the north, passing just right of Glacier Peak, a major Cascade volcano. View looking north from the main peak of Mt. Fernow.

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drainage joins the Wenatchee River which flows into the Columbia River just north of the city of Wenatchee. The drainage of the western side eventually joins the Skykomish River which empties into Puget Sound near the city of Everett.

Previous Geologic Investigations

Geologically, most of the northern Cascades is unknown, though certain restricted areas have been studied. Previous work in the area described in this paper has been in the nature of general reconnaissance only and has not been published apart from being used in the compilation of the Geologic Map of the State of Washington (2,3). This map gives the approximate distribution of the granitic and metamorphic rocks in this area, although the actual boundaries shown are incorrect.

Some additional geologic work has been done in adjacent areas. Before the turn of the century I. C. Russell made several recomnaissance trips in areas to the east and northeast (8,9). To the west of the area described in the present paper, W. S. Smith made a brief petrographic and physiographic study of the Skykomish River basin (13,14,15). To the southeast of the present area, in the vicinity of Chiwaukum Creek, B. M. Page has done work involving structure, petrology, and physiography (7). In an extensive region east of the Stevens Pass-Nason Ridge area, C. L. Willis has done

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detailed work in structure and petrology, the results of which have been published in his recent University of Washington doctorate thesis (20).

Field Conditions

ent area are not ideal but are far better than in most parts of the Northern Cascades, chiefly owing to the presence of U.S. Highway 2. Dense timber and brush cover the lower elevations in the western part of the area. In the eastern part, however, the ground, though timbered, is more open. High, rugged peaks and ridges offer excellent, though not by any means always continuous, exposures. The relief approaches, in some places, 6000 feet, and most of the slopes are very steep. Heavy snows of up to 700 inches in one season prohibit geologic work except during the short summer season.

I spent eight weeks in the field during the summers of 1949 and 1950. Due to a lack of aerial photographs, the mapping had to be done by Brunton compass traverses aided by photographically-enlarged copies of the Chiwaukum and Skykomish quadrangles of the U.S. Geological Survey. Over 300 specimens were collected, from which thin sections were made.

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GEOLOGY AND PETROLOGY OF THE CRYSTALLINE ROCKS

General Statement

Though the Cascades are a topographic unit, their rocks vary greatly in different parts of the Washington section of the range. South of Snoqualmie Pass (Fig. 1), which lies approximately 30 miles southwest of Stevens Pass, the bulk of the exposed rocks are Tertiary volcanics (2,12). North of Snoqualmie Pass the Cascades are a complex mass of metamorphic, sedimentary, and igneous rocks, dominantly of pre-Tertiary age. The rocks described in this paper are mainly metamorphic and granitic rocks of this northern province.

The rocks of the Stevens Pass-Nason Ridge area readily permit a threefold division, both geographically and petrographically (Plate B). The western third of this area, lying both east and west of Stevens Pass and thus straddling the crest of the Cascades, is dominantly composed of granitic rocks, the most abundant type being a quartz diorite. The central third of the area is a series of extremely contorted schists which are the oldest rocks present. The eastern third of the area, extending to Lake Wenatchee, consists of a belt of granitic and mixed gneisses.

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The petrologic and structural description of these rock units is given in chronological sequence.

Schists The management form the

Distribution and Structure

The oldest rocks of the Stevens Pass-Nason Ridge area are a group of schists. They are found in a broad belt east of Stevens Pass between the granitic rocks lying west of Berne and the gneisses lying east of Merritt (Plates A and B). The maximum width of this belt, as measured across the strike, is six miles. The prevailing strike of these schists is northwest-southeast, and this belt was followed along the strike for four miles to the southeast and ten miles to the northwest from the Stevens Pass Highway (U.S. 2). Only further regional mapping will determine the northwest and the southeast terminations of this unit. However, Dr. Peter Misch says that he has observed the same schist unit about 30 miles to the northwest in the Whitechuck River valley west of Glacier Peak (17), and Page (7) has observed similar schists approximately ten miles to the southeast in the vicinity of Chiwaukum Creek.

In spite of the timber cover at the lower elevations, exposures are generally very good. Also, there are numerous road and railway cuts along Nason Creek. At the higher elevations cliffs and sharp ridges offer almost continuous exposures

The petrologic and structural description of these rock units is given in enronological sequence.

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Distribution and Structure

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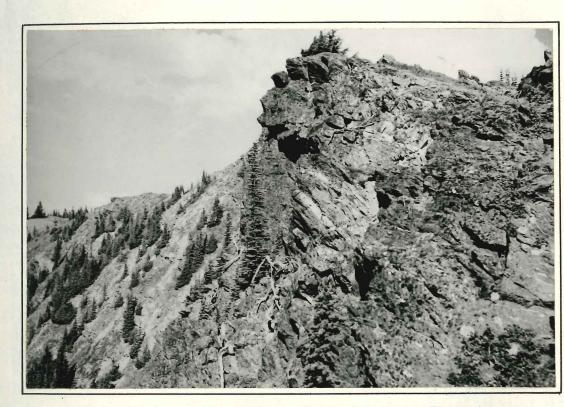
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in the schists. These schists form the highest elevations in the entire area. Prominent among the higher peaks are the Chiwaukum Mountains, lying south of Nason Creek, which attain elevations in excess of 8000 feet. The schists also form the bulk of Nason Ridge, including Mt. Howard (7520 feet) and Rock Mt. (7300 feet). The schists also form some of the lowest elevations in the entire area, being found at elevations less than 2000 feet. The northern ridge of the Chiwaukum Mountains consists of schist forming a series of very steep, north-facing cliffs and narrow, sloping benches. Even more spectacular than this face is the north side of Nason Ridge which overlooks the Little Wenatchee River. Here is a wall which, in many places, is a mile high -- a wall of nearly vertical cliffs and inclined benches. The southerly slopes of the Chiwaukum Mountains and of Nason Ridge are considerably less steep. Every ridge in the schists displays this asymmetery which is probably due to glacial action locally aided by structural control (Plate IV).

The predominant strike in the schists is approximately northwest-southeast (Plate B). In the western part of the schists they are invariably found in isoclinal folds which are readily seen in the field, and it is presumed that any larger structures present are also isoclinal folds. These folds generally have a steep dip to the northeast (Plate V). Near Merritt the strike swings around to nearly east-west, and the dips become more gentle and, though variable, are generally to

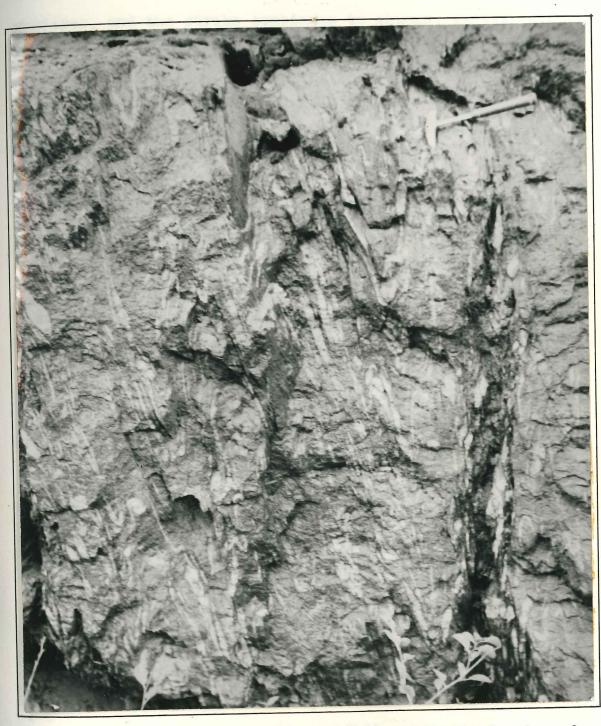
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PLATE IV



Asymmetry of strike ridges in schists. The steeper face to the left is at the head of a cirque; the more gentle slope to the right is a dip slope. North ridge of Mt. Fernow.

PLATE V



Banded biotite-quartz schist. White exudation bands and lenticles of quartz mark the isoclinal folding and steep dips characteristic of these schists. Immediately west of Schilling Creek on U.S. 2.

the north. East of Merritt the schists pass into granitic gneisses, and the strike continues to change, finally becoming northeast-southwest, with moderate dips to the northwest.

Field observations by Willis (20) and the author on the flanks of Dirty Face Peak northeast of Lake Wenatchee show a prevailing strike of northwest-southeast and steep southwest dips.

A coordination of these data appears to indicate that a major structure—a broad northwest-plunging syncline—has been superimposed upon the isoclinally-folded schists and gneisses.

Though petrographically quite variable, in the field the schists present a rather uniform appearance, weathering usually to a dirty reddish-brown color. It is therefore difficult to distinguish different varieties of schist in the field. The various types described in succeeding pages have been differentiated by means of microscopic study.

Petrographically the schists can be divided into two major groups. The predominant type, though variable, is a biotite-quartz schist. A subordinate type, also quite variable, contains hornblende, usually in excess of the biotite.

Biotite-Quartz Schists

These schists are generally isoclinally-folded and much contorted (Plate VI). Their dips are variable, but usually steep. These schists normally exhibit megascopically-visible banding, and there are three distinct kinds of bands (Plate

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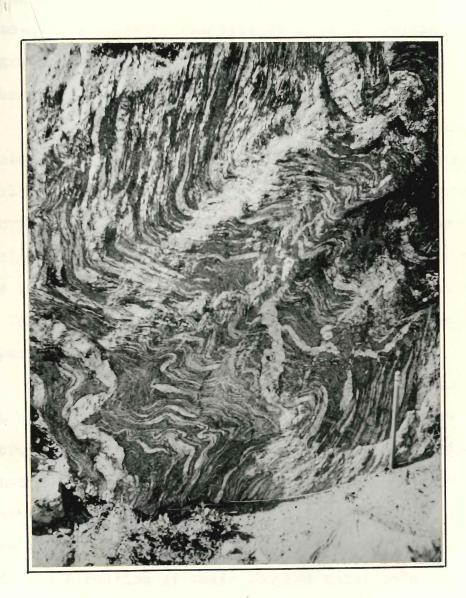
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Biotite-Quarts Schlats

These schiete are generally isocitnally-folded and much contorted (Flate VI). Thair dips are vertable, but usually steep. These schiets negative schiet megatropically-visible bending, and there are three distinct kinds of bands (Flate

PLATE VI



Banded biotite-quartz schist with intricate minor folding. Later cross-cutting quartz-feldspar replacement veins. East slope of Mt. Fernow.

VII).

The most prominent bands, and the widest, are dominantly composed of quartz and commonly exhibit pronounced
pinching and swelling. These alternate with two kinds of
biotite-quartz schist: one type is a thin, greyish, very
fine-grained quartz-rich band; the other is a darker, biotiterich band.

In view of this repetition of alternating bands and lenticles, the rock might be called by some "gneissose," if Tyrrell's definition (16,p.274) were followed. However, most metamorphic petrographers do not follow this usage and would unquestionably classify these rocks as schists. Accordingly, in the present paper the term "gneiss" will be restricted to those fairly coarse-grained foliated rocks possessing a high feldspar content.

Some exposures of the schists show as many as 15 different bands within one inch, yet in others the bands are much thicker, and some of the wider quartz bands may swell to boudin-shaped aggregates up to 18 inches in thickness perpendicular to the foliation of the schist (i.e., in "c"). Such massive segregations of quartz often extend for a score of feet in the direction of their longest axis—this axis paralleling the <u>b</u>-lineation in the rock. Their intermediate axis parallels the <u>a</u>-axis in the schist. Both <u>a</u> and <u>b</u> lie in the foliation plane, <u>s</u> (6,p.45;10,p.57). The prominent banding of

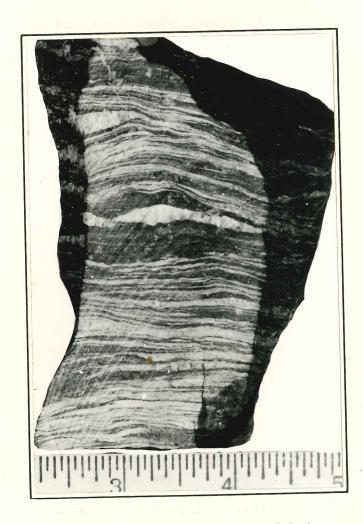
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The most prominent bends, and the widest, are dominsatly composed of quarts and commonly exhibit pronounced
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feet in the direction of their longest axis—this axis paralleling the b-lineation in the root. Their intermediate axis
parallels the a-axis in the achist. Seth a and b lie in the

PLATE VII



BALL TO

Banded biotite-quartz schist with wider quartz exudation bands, thin bands of quartz mosaic, and dark biotite-rich bands. Small, light-colored spots in the biotitic bands are almandine. West flank, Jim Hill Mt. (spec. 1-13-9-49).

the schists makes their minute details of often intricate folding very conspicuous.

Garnet, usually less than a quarter inch in diameter, frequently studs the schistose bands (Plate VII).

A microscopic examination of a typical biotite-quartz schist impresses one not only with the distinct banding but also with the high content of quartz (Plate VIII). Quartz usually comprises 70 to 75 per cent of the rock. The wider quartz bands are composed of large, irregular, crystalloblastic grains of quartz, with small amounts of elongate biotite and accessory graphite usually occupying positions of random orientation in the intergranular spaces. Undulatory extinction and the presence of sheared marginal areas which have subsequently recrystallized, plus the inclusion of elongate biotite grains, indicate that these bands have participated in the deformation of the schist. Occasional small anhedral individuals or irregular aggregates of plagioclase occur between the larger quartz grains. This plagioclase varies from Ab70 to Ab75. It has the same composition as that occurring in the other two kinds of bands which make up the rock. These quartz bands with their elongate biotite inclusions appear to be due to metamorphic differentiation under conditions of active stress. They may be called exudation bands which lie between zones of intense shearing.

the samists makes their minute details of often intricate folding very completences.

Germet, usually less than a quarter inch in diameter, frequently study the schistone bands (Flate VII).

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PLATE VIII



, 1 mm.

(Photomicrograph, crossed nichols)
Banded biotite-quartz schist. Above:
quartz-rich band with large grains of
strained quartz and subordinate
plagioclase. Middle: finer-grained
mosaic of quartz. Below: biotiterich band. Southeast flank of Union
Peak (spec. B-10).

These thicker quartz bands are in most cases adjacent to the thin, greyish, quartz-rich biotite schist bands which consist of a very fine-grained mosaic of strained, irregularly-shaped, usually equi-dimensional quartz, and subordinate biotite and plagioclase (Plates VIII and XI). The over-all structure is best described as granulose, with elongate biotite and subordinate magnetite, graphite, and garnet oriented to form a well-marked but discontinuous foliation.

The third and last type of band, which is darker and rich in biotite, exhibits pronounced foliation (Plate X). A fine-grained, irregular-shaped mosaic of quartz is associated with large quantities of elongate biotite forming layers of longitudinally-varying extent which are often continuous over considerable distances. The biotite is of a reddish-brown to chocolate-brown color, is extremely pleochroic, and usually contains well-developed pleochroic haloes around tiny zircon nuclei. Graphite is frequently aligned along the cleavage planes of the biotite, and grains and irregular masses of magnetite are common inclusions in the biotite.

Generally the schists show two generations of biotite.

The older generation consists of parallel flakes in the plane
of schistosity which are usually 5 to 7 times as long as thick.

At the apices of microscopic folds the biotite has usually been bent, though recrystallization of folded biotite layers in polygonal arcs also occurs. The first generation of biotite is

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PLATE IX



l mm.

(Photomicrograph, plane polarized light) Contorted biotite-quartz schist. Postkinematic crystallization of biotite both along and across the foliation. Graphite bands, marking the foliation, are included in the biotite. Main peak, Mt. Fernow (spec. 1-3-9-49).

PLATE X



I mm.

(Photomicrograph, crossed nichols)
Mica-quartz schist with synkinematic
biotite marking the foliation, and
randomly oriented postkinematic biotite (b) and muscovite (m). Almandine
(a) at lower left. Summit of Nason
Ridge east of Lake Merritt (spec.
B-23c).

PLATE XI



I mm.

(Photomicrograph, crossed nichols)
Almandine porphyroblasts (dark) in
biotite-rich layer of banded biotitequartz schist. West flank, Jim Hill
Mt. (spec. 1-13-9-49).

synkinematic, being the result of crystallization contemporaneous with deformation (Plate X).

The second generation of biotite, usually minor in quantity, consists of irregularly-shaped plates, often without appreciable elongation, which either roughly follow the schistosity marked by the synkinematic biotite or grow across the foliation at various angles. This generation represents a period of dying deformation and a static phase of crystal-lization immediately following it (Plate IX).

Muscovite, present locally in small quantities, displays the same two generations as the biotite. The second generation muscovite usually consists of rather ill-defined and irregularly-bordered grains (Plate X).

To sum up, the typical schist is composed of three distinct types of bands, with quartz and biotite the dominant minerals, and graphite, magnetite, plagioclase, and muscovite present in subordinate quantities. This main type of schist is the basis for quite a number of special varieties which are characterized by the presence of additional constituents, such as one or all of the following minerals: almandine, kyanite, and staurolite.

Almandine may or may not occur in rock types of otherwise identical composition (Plate XI). The almandine displays good examples of different times of crystallization with regard to phases of deformation. Some show a well-defined synkinematic, being the result of orgotalization contemporameous with deformation (Plate N).

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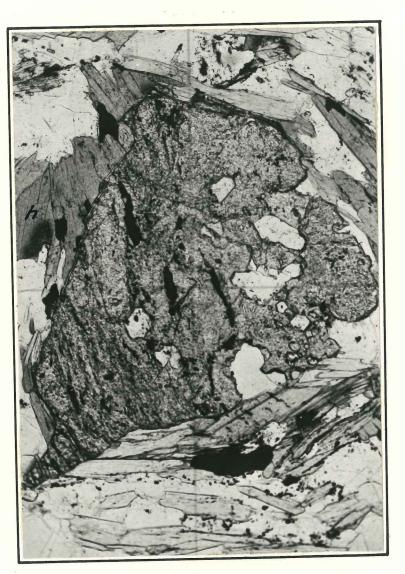
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Almendine may or may not occur in rock types of otherwise identical composition (Flate XI). The almandine displays good examples of different times of drystallication with regard to phases of deformation. Some show a well-defined s-shaped internal <u>s</u> (10,p.57) consisting of graphite and quartz inclusions, indicating rotation during garnet growth. Others exhibit a straight internal <u>s</u> which has been rotated 90° or less, indicating renewed deformation after static garnet growth (Plate XII). In either case the almandine is later than the primary deformation which has formed the <u>s</u> of the schist. The garnet, through crystallization force, has invariably bowed-out the biotite on both sides across the foliation and permitted a random growth of biotite in the "stress shadow areas" resulting from the garnet growth (Plate XII).

Kyanite and staurolite are frequent constituents of the schists and may occur together or separately. Their amount may reach 10 per cent of the rock. Normally confined to the darker, biotite-rich bands of the schist, the kyanite most often forms broad, elongate, tabular plates, the c-axes of the kyanite lying in the plane of schistosity. In many schists, particularly at the axes of folds, the kyanite is bent. Commonly, this kyanite contains an internal sconsisting of graphite. In a few cases the kyanite has grown across the plane of foliation (Plate XIII). This phase of kyanite growth is later than deformation and is obviously due to high temperatures continuing under static conditions.

Staurolite occurs either as rounded, irregular grains or, occasionally, in six-sided, idioblastic cross-sections

PLATE XII



0.5 mm.

(Photomicrograph, plane polarized light) Almandine with an internal sof graphite and magnetite displaying post-crystalline rotation. Plane of foliation of biotite-quartz schist lies from left to right. Randomly oriented biotite has formed in the "stress shadow" areas left and right of the garnet. Biotite plate at upper left contains a dark, pleochroic halo (h) around a small zircon grain. Schilling Creek (spec. 1-15-10-49).

E-skaped internal g (10,9.57) consisting of graphics and quarts inclusions, indicating rotation during garnet growth. Others exhibit a straight internal g union has been rotated go or less, indicating renewed deformation after static garnet growth (Plate XII). In either case the almandine is later than the privary deformation which has formed the g of the schiet. The garnet, through expecialization force, has invariably bowed-out the biotics on both sides across the foliation and permitted a sandom growth of biotic in the garnet growth at the garnet growth areas abadom areas resulting from the garnet growth (Plate XII).

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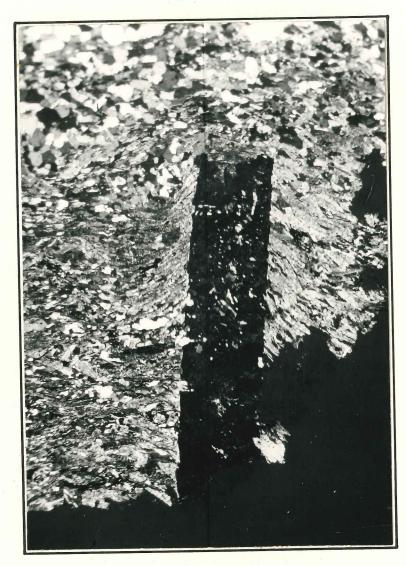
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PLATE XIII



l mm.

(Photomicrograph, crossed nichols)
Postkinematic kyanite idioblast (dark)
transecting foliation of biotitequartz schist. Growing porphyroblast
has bent out the foliation of the
groundmass. Some recrystallization of
biotite, muscovite, and quartz in the
groundmass has produced a very slight
superimposed hornfelsic texture.
South slope of Mt. Howard (spec.
C-15d).

which are usually elongated in the plane of foliation.

Irregularly-shaped inclusions of quartz and graphite are common. This staurolite is in part synkinematic and is in part postkinematic or static (Plate XIV).

On the southwest flank of Rock Mt. are found very fine-grained, highly carbonaceous biotite-quartz schists which appear to contain large (up to 20 mm in length) porphyroblasts of chiastolite with well-developed graphite crosses. Microscopic examination discloses the fact that these porphyroblasts are not composed of chiastolite but are composed of kyanite and staurolite which are pseudomorphs after chiastolite. It is of interest that in this process the graphite crosses of the chiastolite were inherited without apparent change by the kyanite and staurolite (Plate XV). This apparently indicates that a static growth of chiastolite under temperature conditions typical of the warmer part of the mesozone preceded a phase of dynamic metamorphism during which kyanite and staurolite were produced.

A study of many thin sections has convinced me that the schists of this area cannot be assigned to separate kyanite or staurolite zones. These two zones of Barrow's (1) classical scheme do not apply here. In fact, their validity has been questioned by several petrographers, including H. H. Read and Peter Misch. In the area here described, rocks which contain either kyanite or staurolite, as well as rocks

biothos, wnservise, and quartz in the

superingosed in this black basture.

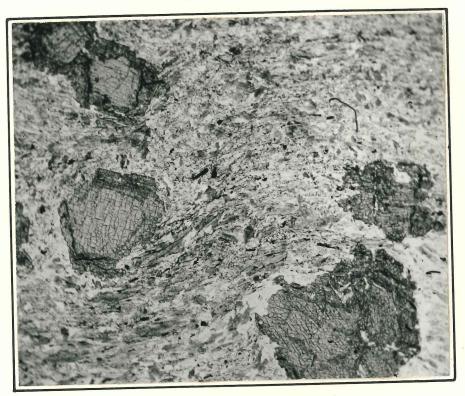
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PLATE XIV

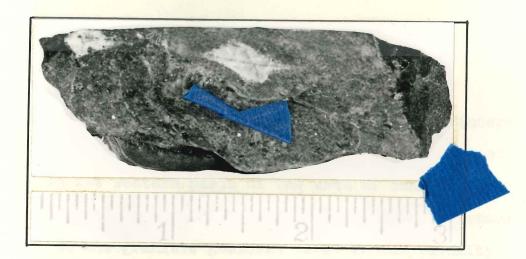


I mm.

(Photomicrograph, plane polarized light) Idioblasts of staurolite in a staurolite-kyanite-biotite-quartz schist. Staurolite has bent out foliation of mica schist matrix. Southeast flank, Rock Mt. (spec. B-12a).

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(Another region) passed particle in a stauroliteelationlasse of rearbite in a stauroliteelation of mice braist. Staurolite • sea bent out roliation of mice schiet. elation catheors I and Rock Mt. (appears PLATE XV



Kyanite and staurolite forming pseudomorphs after chiastolite (light-colored areas) in a fine-grained graphite-staurolite-kyanite-biotite-quartz schist. Southeast flank, Rock Mt. (spec. B-12b).

containing both, sometimes in oriented intergrowth, are closely associated and irregularly distributed, and no zonal pattern whatsoever is indicated.

In view of what has been written above, and inasmuch as the kyanite and staurolite are clearly contemporaneous in many rocks of this area, the quartz-biotite schists are assigned to the kyanite-staurolite zone. This zone corresponds to the hotter part of the medium grade or mesozone (Grubenmann, 5) of regional metamorphism.

Hornblende-Bearing Schists

Subordinate hornblende-bearing schists are intercalated in the dominant biotite-quartz schists. They occur most frequently in the western parts of the area of schists, particularly near the town of Berne. There are also occurrences adjacent to the granitic gneisses found in the vicinity of Merritt. Similar hornblende-bearing schists have been described by Page (7) in the vicinity of Chiwaukum Creek. Hornfelsized remnants of these hornblende-bearing schists occur in the migmatite zones at the contacts of the schists with the granitic rocks to the west and the granitic gneisses to the east. The hornblende-bearing schists occupy zones having a maximum-observed width across the strike of 300 yards.

Most of the hornblende-bearing schists are rich in biotite and are often megascopically indistinguishable from

kjandes and structive forming preddemorphs after ellestelles (Light-colored arcts) in a fine-grained groundstander biotive-quartz schiet. Southeast flamit, took Mt. (spec. B-12b).

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monly too fine-grained to be megascopically visible. Both the major schist types are usually banded, but the bands in the hornblende-bearing schists are usually thinner and less conspicuous. The wide quartz-exudation bands so typical of the biotite-quartz schists are in most cases absent. A dark, greenish hue occasionally helps one to recognize the hornblende-bearing schists in the field.

Microscopic examination of the hornblende-bearing schists shows that they are highly variable. No one particular occurrence can be designated as typical. The only common characteristics of these rocks are their schistosity and the presence as a major constituent of hornblende.

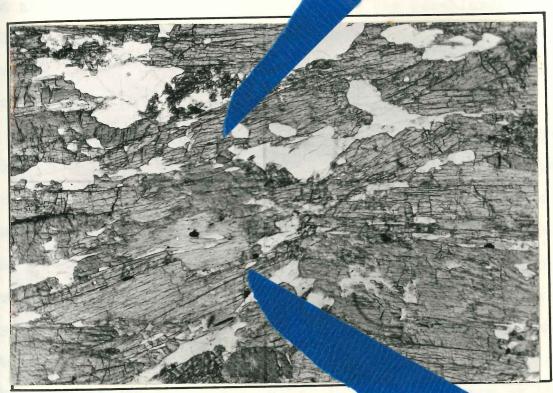
The amount of hornblende varies from extreme values of about 5 per cent to as much as 90 per cent of the rock but is commonly between 20 and 40 per cent. Other minerals in these rocks are biotite, quartz, plagioclase, and accessories. The hornblende is usually of a pale green color, being pleochroic from almost colorless to olive-green. The optical properties indicate an amphibole intermediate between actinolite and common green hornblende. Therefore, this amphibole will be referred to as actinolitic hornblende. In a few cases the amphibole is common green hornblende. This applies to all those rock varieties with an unusually high amphibole content. However, such true amphibolites are rare (Plate XVI).

the ordinary biotite-quarts schists. The hornblende is comsonly too fine-grained to be megascopically visible. Both the
sonly too fine-grained to be megascopically visible. Both the
safer schist types are usually banded, but the bands in the
normblende-bearing schists are usually thinner and less conspicuose. The wide quarts-saudation cands so typical of the
biotite-quarts schists are in most dases absent. A darm,
biotite-quarts schists are in most dases absent. A darm,
crosnish has coccasionally helps one to recognize the here-

staroscopic examination of the hornblende-bearing achieve chor they are highly variable. No one particular contrate chors can be designated as typical. The only conson of are these rooms are that schiztosity and the characteristics of these rooms are that achistosity and the

The amount of mornblends varies from extreme values of about 5 per cent to as much as 30 per cent of the rock but is comeanly between 20 and 40 per cent. Other minerals in these rocks are bictite, quarty, plagicolase, and ecosmorfice. The hornblends is usually of a pale green color, being pleachroic from almost coloriess to olive-green. The optical properties indicate an amphibole intermediate between softmelite and common green hornblends. Therefore, this amphibole will be referred to as sciinalitic hornblends. In a faw cabes the suphibole is common to as sciinalitic hornblends. This applies to all finese rock varieties with an unusually high amphibole content.

PLATE XVI



I mm.

(Photomicrograph, plane polarized light) abolite common green hornblende in subparallel arrangement; subordinate plagioclase and quartz. Divide between Butcher and Kahler Creeks (spec. B-36).

The hornblende mostly occurs in sub-equidimensional grains in an imperfect subparallel arrangement. Much of it has been recrystallized after the end of deformation. Prisms of synkinematic hornblende do, however, occur, and these of synkinematic hornblende do, however, occur, and these accentuate the schistosity. In the hornfelsized zones adjacent to granitic rocks, recrystallization of the hornblende has to granitic rocks, recrystallization of the hornblende has almost destroyed the original schistosity as far as a preferred orientation of minerals is concerned. However, the over-all banding has survived.

blende in quantity. Usually the biotite and the hornblende are intimately mingled in the fabric of the rock. Only in a few localities has an alternation of biotite- and hornblende-rich layers been observed. As in the case of the hornblende, rich layers been observed. As in the case of the hornblende, two generations of biotite are evident. The first generation is synkinematic; the second is postkinematic and is dominant. Much of the biotite has formed from the actinolitic hornblende. This biotite may follow the relict schistosity marked by the synkinematic hornblende, or it may grow across the foliation at various angles. Wherever biotitization has occurred, irregular aggregates of magnetite become common. In a few cases biotitization has almost eliminated the hornblende.

Quartz is usually present and varies in quantity from an accessory mineral to a major component. It may be almost lacking in those few amphibolites which are rich in common

The hornblende mostly occars in sub-equidimentional rains in an imperfect subparable; arrangement. Much of it was been recrystallized after the end of deformation. Frimm of synkingsatic hornblende do, however, occur, and these dates acceptuate the schizosity. In the hornfelsized somes adjacent to granitic rocks, recrystallization of the hornblende has almost destroyed the original schizosity as far as a preferred crientation of minerals is concerned. However, the over-ell

planeldered and bas estioned and vilamed . viliment at ebreid is symbole to be businesside and is dominant. nelisticl end eacres worm yew it to ebneldmen elismenting well a mi . Hommeo emouad estimate to resease age aslugared sering is those few as hibolites water are rich in compan green hornblende. The amount of quartz tends to be inversely proportional to the amount of hornblende.

Plagioclase usually occurs in minor quantities. It is present in all quartz-bearing varieties, and in those amphibolites which contain common green hornblende the plagioclase is far more prevalent than the quartz. In the hornfelsized hornblende-bearing schists found in migmatitic zones there has evidently been sufficient introduction of sodium and silica to cause the appearance of plagioclase at the expense of quartz. The plagioclase is more calcic than that of the biotite-quartz schists, and it varies in composition from Ab₆₀ to Ab₆₅.

Accessory almandine may be present but is never as prevalent as in the biotite-quartz schists.

Regional retrogressive alteration has strongly affected many of these hornblende-bearing schists. The biotite is often completely altered to chlorite. The pleochroic haloes around zircon nuclei characteristic of the biotite are inherited by this chlorite. Epidote, zoisite, and clinozoisite are frequent alteration products of plagioclase and hornblende. Sericite has also formed from plagioclase, often to such an extent that the type of plagioclase is nondeterminable. Some bent feld-spars are evidences of some deformation during this retrogressive phase.

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achieve, and it varies in composition from Abgo to Abga.

elegration products of plagforlase and normblende. Sericisa tent they are dess of neilo , saclosized mort bewood oris and the type of plagiceless it nondeserminable. Some bent fold-

Genetic Evaluation the symmetry matter and evertiments The petrographic features of the major types of schist have been described above. A genetic evaluation of these features appears to indicate the following sequence of events.

- 1. A thick sequence of sediments formed the material from which the schists were made. The bulk of these sediments were argillites rich in silica and alumina. The alumina excess of these rocks, as demonstrated by the development of kyanite, staurolite, and local chiastolite, is evidence that the original rocks were argillaceous sediments. The hornblendebearing schists and the subordinate amphibolites were derived either from dolomitic argillites or from tuffs of predominantly intermediate, and subordinately basic, composition.
 - 2. Intense isoclinal folding with concomitant synkinematic regional metamorphism of medium grade occurred, and a schistose structure was produced. As temperature rose to that of the kyanite zone, kyanite, staurolite, and almandine developed. These minerals generally occur in porphyroblasts postdating the main phase of deformation during which the schistosity was produced, but recurrent deformation is indicated by rotated almandine, and kyanite with a pronounced internal s. Some minor folding, frequently deforming the foliation planes, also belongs in a postschistosity phase of deformation (Plates IX and X) . manufacture was they along a guarter whis Buttomer Grack. In it successful as by a breggist of a

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The petrographic tentures of the major types of schick maye been described above. A genetic evaluation of these less tures appears to indicate the following sequence of events.

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- 3. Succeeding the synkinematic metamorphism and continuous with it, a static phase of crystallization occurred. Mesozonal temperatures persisted, and some kyanite, biotite, and muscovite grew across the schistosity with random orientation (Plates IX, X and XIII).
- 4. As temperatures decreased at the end of metamorphism, retrogressive minerals such as muscovite, sericite, chlorite, and epidote formed. Some of the sericite and chlorite present, however, is due to recent weathering.
- 5. The last major event was tectonic and produced a large, open, plunging syncline (cf., page 14) superimposed on the isoclinal folding of the schists.

Gneisses

Distribution and Associations

About one mile west of Merritt (Plate A) the schists grade across their strike into a migmatitic zone in which gneiss and schist occur in varying proportions. This migmatite zone continues to a point just east of Merritt where a transition to an area of dominant gneiss occurs. These gneisses then continue eastward for approximately four miles to a fault contact with the supposedly Paleocene continental sediments of the Swauk formation (2,11,19,20). This fault trends north-south and lies about a quarter mile east of Butcher Creek. It is accompanied by a brecciated zone

3. Succeeding the syndinements hetenorphism and continuous with it, a static phase of crystallication occurred. Mesoscial componentures perstated, and nows kyanite, biolite, and muscovited grew across the schistesity with random orientation (Flatus IX, IX and III).

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approximately 200 yards in width.

The gneisses, however, are not confined to a zone only four miles in width in other parts of this general area.

During a reconnaissance trip to the northern shore of Lake Wenatchee similar gneiss was found to occur on the flanks of Dirty Face Peak (see Chiwaukum quadrangle, 17, a). Willis (20) has shown that similar gneisses extend farther to the east. Certain types of gneisses found in the Nason Ridge area are identical with rocks occurring in the Entiat Mountains east of the graben which contains Lake Wenatchee and the Swauk sediments. Waters (18) has found "biotite gneisses," that appear to be similar, grading into the granodioritic gneisses on the borders of the Chelan batholith.

Petrology and Structure

The gneisses of the Nason Ridge area are fine to medium-grained and approach a granitic composition. However, they are highly variable in texture and, to a somewhat lesser extent, in composition. In the migmatitic zone west of Merritt there occur sheets of leucocratic gneisses intercalated in the darker schists, forming a lit-par-lit structure (Plate XVII). Layers of both rocks vary in thickness from an inch to an exceptional maximum of six feet, the average being about six inches. The foliation of schist and gneiss is parallel.

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PLATE XVII



Banded gneiss. Fine-grained highly felspathic layers and medium-grained hornfelsic schist material. One-quarter mile west of Merritt (spec. 7b-25-3-50).

The gneissic layers found in this lit-par-lit structure are composed of a fine- to medium-grained rock with good foliation. Feldspar and quartz are the dominant constituents. Subordinate muscovite and/or biotite, in parallel arrangement, define the foliation.

These gneissic layers grade into the schists. Usually the schists are biotite-quartz schists, but hornblende schists are also found. Most of the schistose layers are hornfelsized to some degree, but the quartz-rich bands and boudins so characteristic of the biotite-quartz schists are usually still in evidence. Felspathization has formed thin bands, rich in feldspar, along the planes of schistosity (Plate XVIII).

within the migmatite zone west of Merritt, and especially at the railway overpass near the confluence of Whitepine and Nason Creeks, there occurs a second variety of gneiss. It consists of all possible gradations between hornblende schists and fine- to medium-grained granitic gneisses, some of which are almost structureless. The schists have been considerably recrystallized and have a hornfelsic appearance. Along the planes of relict schistosity of these hornfelsized schists augen and lenticular aggregates of feldspar occur (Plate XVIII). These hornfelsic schists grade into more gneissic rocks containing skialiths (Goodspeed, 4)--shadowy relics of incompletely transformed schist. The relict schistosity present in these skialiths is parallel to that of both the

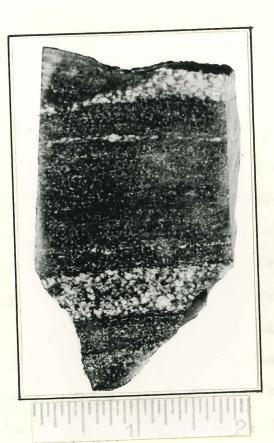
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PLATE XVIII



Banded gneiss. Granitoid bands parallel the relict foliation of a hornfelsized and felspathized hornblende-quartz schist. One-quarter mile west of Alpine Lookout, Nason Ridge (spec. B-29a).

enclosing gneiss and the adjacent schist. The skialith-bearing gneiss grades into gneisses free of relict inclusions. It is important to emphasize the parallelism of the foliation in schists, skialiths, and gneisses.

by a zone of dominant gneiss. This gneiss is quartz dioritic in composition. The layers of schist found in the lit-par-lit structures near Merritt are lacking. But narrow, dark, micaceous layers, up to one inch in thickness, remain as relics of the schist bands (Plate XX, A). The gneiss often becomes coarser-grained, and the foliation less well-defined (Plate XX, B). Feldspar becomes the major constituent, with quartz minor, and muscovite and biotite mark the foliation. In a few places these gneisses grade into almost directionless granitic rocks. However, even in these relatively directionless rocks there occur occasional very thin (one-quarter inch maximum thickness) micaceous layers with attitudes still parallel to those of the adjacent, more clearly-foliated rocks.

All gradations between schist and gneiss, and gneiss and structureless granitic rocks, may be observed in this area.

Much of the relatively structureless granitic rock of this gneissic area is fine-grained and occurs in steep-sided, irregularly-shaped bodies which transect the gneissic structures. Up to 40 feet in width, these bodies have gradational borders with the gneisses. The rock of these cross-cutting

enclosing gneiss and the adjacent schist. The skialith-bearing gneiss grades into gneisses free of relict inclusions. It is important to emphasize the parallelism of the foliation in schists, skialiths, and gneisses.

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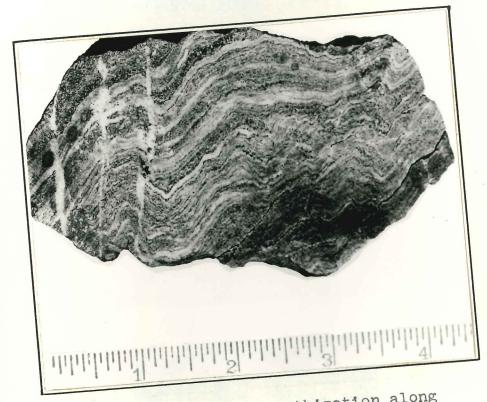
enclosing gnetos and the adjacent schist. The skialith-bearing gnetos grades into gnetoses free of reliet inclusions. It is to gnetose the parallelism of the foliation in contate. singlishe, and gnetoses.

To the east the migmatite come of Marritt is succeeded by a mome of dominant gnetes. This gnets is quartz dioritic in composition. The layers of schist found in the littpar-lit surgatures near Herritt are lacking. But marrow, dark, wicaresous layers, up to one inch in thickness, remain as relics of the schist bants (Plate XX, A). The ghoise often becomes the schist bants (Plate XX, A). The ghoise often becomes in, B). Weldspar becomes the major constituent, with quartz minor, and wascovite and biotite mark the foliation. In a few places these gnetages into almost directionless granitic focks. However, even in these relatively directionless rocks there occur occasional very thin (one-quarter inch maximum thore of the edjacent, more clearly-foliated rocks.

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PLATE XIX



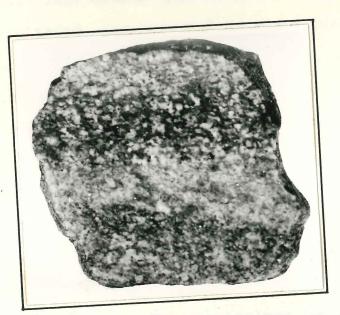
Banded gneiss. Felspathization along planes of relict foliation in a hornblende-quartz schist. Later, hornblende-quartz schist. Later, cross-cutting, fracture-controlled replacement veins contain microcline, plagioclase, and quartz. South flank of Mt. Howard (spec. C-15c).

PLATE XX



A. Banded gneiss. Mafic minerals mark the relict foliation. One-quarter mile west of Alpine Lookout, Nason Ridge (spec. B-29).





B. Medium-grained banded quartz dioritic gneiss. Foliation marked by alternations of lighter and darker bands varying in mafic mineral content. Summit of Nason Ridge, north of Lake Merritt (spec. B-25).

bodies consists chiefly of feldspar, with some quartz and very few dark minerals. Often, however, relics of gneiss and, occasionally, of schist, occur within these granitic zones. Usually, but not always, such inclusions have a relict schistosity which is parallel to that of adjacent gneissic or schistose rocks.

A microscopic examination of the gneisses shows considerable compositional and textural variability, especially in the migmatitic areas at contacts of the schist and gneiss. However, most of the gneiss forming the light-colored layers in the banded rocks west of Merritt is essentially of the same type as that of most of the rock composing the gneissic area east of Merritt. This common type of gneiss is usually fine-grained, well-foliated, and composed of plagioclase, quartz, muscovite, with subordinate biotite, hornblende, potash feld-spar, magnetite, almandine, zircon, and apatite, and retrogressive clinozoisite, epidote, muscovite, sericite, and chlorite.

Plagioclase is the most abundant mineral. It usually forms at least half and occasionally as much as 75 per cent of the rock. The plagioclase occurs as anhedral, irregularly-shaped, crenulated crystals, with a tendency to be elongated in the plane of foliation. The plagioclase individuals interlock, one with another, and with other minerals, in an intricate fashion. The average size of the plagioclase is about

bodies consists chiefly of feldspar, with some quarts and very few dark winerals. Often, however, relics of gneiss and, occasionally, of schist, occur within these granitic zones. Usually, but not always, such inclusions have a relict schist-offty which is parallel to that of adjacent gneissic or settetoss rocks.

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2 mm, but some porphyroblasts reach twice this size. Albite twinning is common, and Carlsbad and pericline twins also occur. Composite twinning is common, and involved zoning is occasionally present.

The larger plagioclase porphyroblasts are filled with inclusions of quartz, muscovite, and often irregular grains of secondary clinozoisite and epidote (Plate XXI). Usually the plagioclase is bent, sometimes in an undulating fashion.

The usual composition of the plagioclase varies from Ab65 to Ab75. Most is about Ab70. However, where hornblende is the main mafic mineral the plagioclase is more calcie, averaging about Ab60 (Plate XXII, A and B). A few of the zoned plagioclases show more calcic cores and more sodic rims.

Quartz, in anhedral crystals, may form up to 25 per cent of the rock. The average amount is about 15 per cent.

This quartz is strained and displays undulatory extinction.

The quartz is intimately intergrown with the plagioclase, and the quartz is intimately intergrown with the plagioclase in many cases it is completely enclosed within the plagioclase crystals (Plate XXI). Myrmekitic growth of quartz and feldsparerystals (Plate XXI). Myrmekitic growth of quartz and feldsparerystals (Plate XXI).

The most common mica present is muscovite. Two generations are recognizable. The first generation is clear, elongated in the plane of foliation and has ragged terminations. This earlier muscovite commonly has parallel orientation and gives the rock a well-marked, though discontinuous,

only but some porphyroblasts reach twice this size. Albite cannon, and Carlabad and perioline twing also cannon, and Carlabad and perioline twing is common, and involved coming is

The lerger plegtociese porphyroblasts are filled with inclusions of quarts, muscovite, and often irregular grains of condary discretists and spidots (Pints XXI). Describy the stagiociase is bent, comestmes in an undulating issuich.

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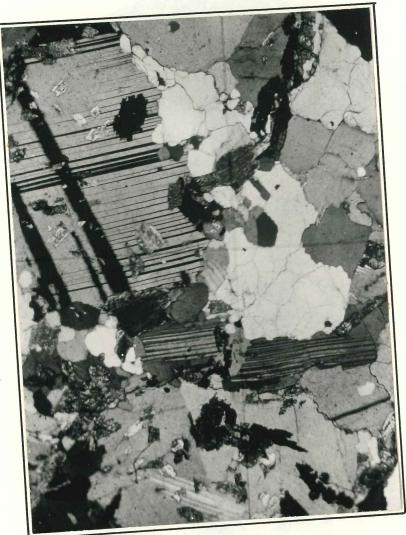
Square, in antestal expetals, may form up to 25 per come of the rook. The average anount is about 15 per cent.

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The most common also present is unscovite. Two genendtions are recognizable. The first generation is elear, compained in the plane of foliation and has regged terminacions. This earlier muscovite domnonly has parallel erients-

PLATE XXI



I mm.

(Photomicrograph, crossed nichols)
Oligoclase porphyroblast (upper left)
containing inclusions of quartz,
biotite, and muscovite. Deformed
plagioclase (lower right). Quartz
plagioclase (lower right). Quartz
diorite gneiss. Lake Merritt (spec.
B-24).

PLATE XXII

B

(Photomicrographs: A, plane polarized light; B, crossed nichols) Felspathized amphibolite. Andesine almost equals common green hornblende. Andertz very minor. Foliation disturbed by parquartz very minor. Foliation of hornblende. Summit, tial recrystallization of hornblende. B-15). Nason Ridge, east of Lake Merritt (spec. B-15).

foliation. Occasionally the muscovite can be seen to have formed from the alteration of biotite. Much of this muscovite is presumed to have been derived from biotite, inasmuch as remnants of schist within the bands of gneiss, as well as adjacent bands of schist, are rich in biotite. In addition to this earlier muscovite, some large, irregularly-shaped plates of muscovite grow across the foliation. This later muscovite is usually turbid in appearance and has ill-defined margins. Some of this later muscovite can be seen altered from plagioclase. The ground more as a season when the season were the season with the se

Clinozoisite, epidote, and occasional zoisite may form as much as 10 per cent of the rock. They occur as irregular grains in the plagioclase and also in the intergranular spaces of the rock. Occasionally these minerals can be seen closely associated with biotite, in which case they are presumed to have formed as a result of biotitization of earlier hornblende. This interpretation is usually supported by the presence of hornblende in adjacent layers of schist and occasional, partially-biotitized, remnants of hornblende preserved in the gneiss. In other cases these minerals are an alteration product of the plagioclase, and thus may be considered as indicative of a retrogressive phase of metamorphism.

Almandine, with inclusions of quartz, biotite, and occasional clinozoisite, is an accessory.

rored from the alteration of biotite. Much of this muscovite is presumed to have been derived from biotite; inacmuch es a presumed to have been derived from biotite; inacmuch es remains of schict within the bands of gaetas, as well as adjacent bands of schict, are rich in biotite. In addition to this carlier mascovite, some large, irregularly-shaped plates of cuscovite grow scross the foliation. This later muscovite is usually turbid in appearance and has ill-defined margins.

Climosolaite, epidote, and occasional moisite may form an amon as 10 per cent of the rock. They occur as irregular epaces craims in the playlociase and also in the intergranular spaces of the rock. Cocasionally these minerals can be seen closely assembled with biotite, in which case they are presumed to have formed as a result of biotitization of earlier hornolande. This interpretation is usually supported by the presence of normalands in adjacent layers of schiot and occasional, partiably biotitized, remaints of normalands preserved in the greiss. In other cases these minerals are an alteration product of the plagioclass, and thus may be considered as indicative of a retrogressive phase of metamorphism.

Almendine, with inclusions of quartz, bioutte, and coossions elinosoisite, is an accessory.

In the migmatitic areas, especially west of Merritt, this gneiss is transitional with the schists. Within a few inches the gneiss grades into biotite-quartz schists or hornblende-bearing schists. The schist bands which are immediately adjacent to the gneiss bands have undergone a phase of static recrystallization. As a result, they have acquired a superimposed hornfelsic texture and have partially lost their schistosity (Plates XVII and XVIII). The biotite and muscovite, and the hornblende, of these hornfelsized schists have frequently grown across the relict schistosity. Small porphyroblasts of plagioclase of the same composition as in the gneiss form thin bands in the schists parallel to their schistosity. As the gneiss is approached, these bands become wider and the porphyroblasts larger.

A comparison of adjoining layers of schist and gneiss often shows the two do not differ very radically in texture or mineral composition. Whereas quartz is usually the dominant constituent in the schists, plagioclase assumes that position in the gneisses. Most of the biotite of the schists becomes muscovite in the gneisses, and the total amount of mica is reduced. Where hornblende was a major constituent of the schist, biotite, muscovite, clinozoisite, and epidote are present in the adjoining gneiss. Aside from these main differences, the other mineral constituents of the gneisses and schists are identical in type and, usually, in quantity. For

In the migratitic areas, especially west of Merrici, the grant to translations and the the sentences of salary almost the translations of the contract of the contr to staine strang-evitoid offi seberg saleng off salent oletely adjagant to the gnaiss bands have undergone a phase of a bertapos even yeds, thes result, they have acquired a .woodstood ty (Plates MyIX and AVIII). The blowing and mussow-Traquently grown serous the reliet schistosity. Small por-

TO STUDIES HE THE TO SO NOT GAT TRACTED TO THE TRACTE OF T apacond staines ond to establish to see accious end of sa sois to tanous istor end the teastern end at edivorses reduced. Where hard-bends was a major constituent of the piecent in the adjoining gnotes. Aside from these wain diflerences, the other mineral constituents of the gheleace and

example, the almandine so prevalent in many of the schists is inherited by the gneiss.

In the gneiss described above, and also in many of its varieties, potash feldspar may be found. Usually this is microcline. Almost invariably the microcline is found in porphyroblasts along what appear to be rather narrow zones transecting the gneissic structure. These microcline porphyroblasts average 2 mm, but exceptionally attain 7 or 8 mm in size. The microcline is normally associated with a very noticeable vermicular growth of quartz and plagioclase. Several occurrences show the plagioclase being engulfed by microcline. Middition to sodium and william the winds when ploude one

Genetic Interpretation Both structural field evidence and microscopic study of the gneisses near Merritt indicate that they have been derived from the schists through processes of syn- and postkinematic metasomatism.

In the field it is observed that the contacts between schists and gneisses are invariably gradational. In addition, the foliation of adjacent gneisses and schists is usually parallel; this equally applies where thin and long lenticular bands of schist are completely enclosed in gneiss, as well as where smaller relics of schist occur in the gneiss. Mellor. The electron dilicates present in the schlete,

ensured by the almandine so prevalent in amage of the soniate in

In the gnotes described above, and slap in many of its varieties, potesh feldophr say be found. Stually this in the startouthe. Almost invertably the migrapline is found in normalizational states along what appear to be rather narrow somes of the characters at the gnaisaic structure. These microdine porphysation is average 2 mm, but exceptionally actain 7 or 6 mm incleable varsicular growth of quartz and plagiculase. New oral occurrences show the plagiculase being engulfed by and courrences show the plagiculase being engulfed by microdine.

Sametic Interpretation

Both structural field evidence and microscopic study of the gneleses near marritt indicate that they have been derived from the schists through processes of syn- and post-

In the field it is observed that the contacts between schists and gneisses are invariably gradational. In addition, the foliation of edjacent gnaisses and schists in usually parallel; this equally applies where thin and long lenatoular bands of schiot are completely enclosed in gneiss, as well as where smaller relies of schist occur in the gneiss.

The petrographic features of the gneisses and their contacts with the schists have been described above. A genetic evaluation of these features indicates the following probable sequence of events.

1. During, and after, the orogenic metamorphism which isochemically formed the schists, an introduction of sodium and silica occurred in the areas now occupied by gneisses. This assumption is necessary to explain the presence of plagioclase as the dominant constituent of the gneisses, in contrast to the plagioclase-poor schists. At the same time the hornblende of the hornblende-bearing varieties of schist was biotitized, thus indicating an introduction of potassium in addition to sodium and silica. At a later stage biotite was extensively, in some cases even completely, converted to muscovite. The biotitization of hornblende released mainly calcium, whereas the transformation of biotite into muscovite set free magnesium and iron. Apart from these mineral transformations, the total amount of mica also decreased during the felspathization responsbile for the formation of the gneisses. This led to a further release of iron and magnesium, as well as aluminum which later was utilized in the production of metasomatic feldspar. No kyanite or staurolite are preserved in the gneisses.

The genesis of the plagioclase may be outlined as follows: The aluminum silicates present in the schists;

The perrographic features of the guelases and their contacts with the schiats have been described above. A genetic evaluation of these features indicates the following probable sequence of events.

and allies occurred in the greas now occupied by gneisses. This assumption is necessary to explain the presence of plagiaddition to sodium and silica. At a later stage biotite was covice. The bictitization of normblende released mainly of formations, the total amount of sica size decreased daring the felspainization responsible for the foraction of the guelsmen. This led to a further release of tron and magnesiamy as mellas aluminum which later was willied in the production of Asvasometic feldaper. As Lyanito or staurolite are preserved

The genesis of the plagioulase may be outlined as

further aluminum set free by the breaking-up of mica; some of the quartz of the schists; and the calcium set free as a result of biotitization of hornblende: all combined with the metasomatically-introduced sodium and silica (cf., above) to form the plagioclase which is so dominant in the gneisses. This plagioclase varies from oligoclase to andesine (cf., page 46). Where hornblende was a major constituent of the schists, the relatively large amount of calcium released by biotitization of the hornblende tended to make a comparatively more calcic plagioclase approximating Ab₆₀ in composition. Where biotite was the dominant mafic in the schist, and hornblende was either minor or absent, the plagioclase of the resultant gneisses was more sodic and approximated Ab₇₅ in composition. This variability can definitely be correlated with the original composition of adjacent schists.

2. The processes described in (1) continued after the end of deformation. High temperatures and sodium and silica introduction evidently continued, for large porphyroblasts of plagicclase, with haphazard orientation, developed during this postkinematic or static phase of felspathization, both in the gneisses and the adjacent schists. Transverse grains of biotite, muscovite, and hornblende grew across the foliation of the schists, and to a certain extent a hornfelsic texture was superimposed on the schistosity. Hornfelsizing is especially marked where schists are adjacent to gneisses (Plate XVII).

forther sluminum set free by the breaking-up of mich; seme of as as earl des aminiso only bas (staines only to zirsup one result of michiganitin or hormblende: all combined with one of (eveds .. le) sailie bus mulbos besulcatur-vilacitasceed an sate to institute northlende was a major constituent of the 2. The provesses described in (1) continued after the end of deformation. High temperatures and sodies and silica introdecion evidently continued, for large perphyrobiasts of planted bequiere, with haphanerd orientation, developed during this postkindmatte or statte phase of felapathization, both in the new eruixes elelelared a juezza extent a bornfeleic texture was

3. Following the making of these gneisses, widespread fracturing appears to have occurred. A system of cross-cutting fractures was formed along which dike-like and some more irregular bodies of predominantly fine-grained granitoid rock were produced, both in the gneisses and the schists. These transecting bodies of granitoid rocks are usually considerably longer than wide and most usually have a dike-like over-all shape. Often one contact is rather well-defined, suggesting a pre-granitic cross-cutting fracture as a marginal control. The other contact of such bodies is generally irregular in detail and gradational with the country rock. In some of these granitoid bodies haphazardly-arranged inclusions of schist and gneiss are found, suggesting a fault breccia which has been invaded by the granitic materials (Plate XXIII). In other cases the inclusions have attitudes parallel to those of the surrounding schists or gneiss and obviously have not been displaced. Flow structures parallel to the longer axes of these granitoid bodies are in most cases absent, and not infrequently the parallel structure of the enclosing gneiss or schist can be traced across the dike-like bodies as a relict structure.

These cross-cutting dike-like bodies commonly consist of a fine-grained, "salt and pepper"-like granitoid rock.

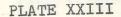
Microscopic examination shows that this granitoid material grades into the country rock at one or both contacts. The

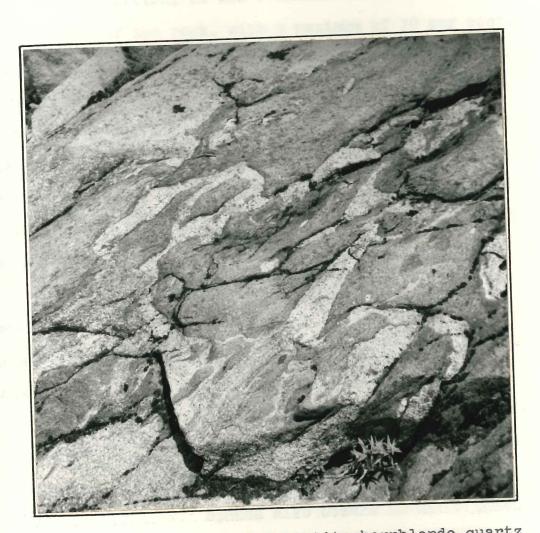
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Migmatite zone. Brecciated biotite-hornblende-quartz schists partially replaced by granitic materials. Inclusions of schist material vary from skialiths to hornfelsized schists. Southeast spur of Union Peak.

Algmatite some. Bracelated biolite-norming declared as a schief particily regimes to a realfigurations of schief areatist was from polations to normical street schiefs. Continue to a schiefs.

average size of the mineral components is 0.2 to 0.5 mm, though occasional pegmatitic examples may have crystals as large as 20 mm in size. Plagioclase, varying from Ab₆₅ to Ab₇₅ in composition, is the dominant mineral, and it averages 60 per cent of the rock, with a maximum of 70 per cent. The larger plagioclase crystals, usually around 0.5 mm in size, commonly approximate Ab₆₅ in composition, with the smaller, later crystals being more sodic. In all cases the plagioclase is anhedral and shows irregular margins characteristic of crystalloblastic growth. The smaller, more sodic plagioclase grains grow at the expense of the larger, more calcic plagioclase, as well as of the quartz and biotite.

Quartz averages 15 per cent of the rock and forms anhedra varying in size from large, irregular grains to smaller, more rounded crystals formed in the intergranular spaces.

ent and is haphazardly-arranged in irregular plates that usually possess ragged, fuzzy terminations and vary in size from 0.1 to 0.5 mm. Sphene also occurs in minor quantities.

These cross-cutting granitic bodies closely approach a quartz dioritic rock in composition.

An examination of many of these dike-like bodies leads to the conclusion that the majority have formed by replacement in situ. Occasionally, however, flow structures have developed

everage cise of the mineral components is 0.2 to 0.5 mm. be in composition, is the doublest mineral, and it everages so year cant of the rock, with a maximum of 70 per cent. The logic planteciase crystals, wagally around 0.3 am in cise, organishing growth. The smaller, more souls planticlese column grow me the expense of the larger, more valoue playin-. sitioid bus straup out to as flow as . sesio

of entery varying in size from large, irregular grains to

from 0.1 to 0.5 mm. Sphere also cocars in minor quantities.

in the conclusion that the majority bays formed by replacement

parallel to the dike walls, and the dike is interpreted as being a mobilized migmatite which has become locally intrusive.

In addition to the minerals described above, occasional porphyroblasts of microcline are found which encreach upon and engulf plagioclase, quartz, and the other constituents of these dike-like bodies (cf., page 51). These microcline porphyroblasts always occur in narrow, often microscopic, vein-like elongate zones transecting the pre-existing dike and the adjacent gneisses. Invariably this microcline is associated with a vermicular growth of quartz and plagioclase. The presence of this potash feldspar suggests a potassium introduction during a postkinematic phase of crystallization.

4. The last event is the formation of epidote and sericite from the plagioclase, and chlorite from the biotite of the gneisses. Apparently the low temperature minerals were formed during a phase of retrogression at the end of metamorphism when temperatures were falling, but part of the sericite and chlorite is due to recent weathering.

Granitic Rocks

Distribution

A varied group of granitic rocks underlies a large area west of the schists. They compose the Stevens Pass region proper and the peaks lying north and south of the Pass along the Cascade Crest. The area of these granitic rocks

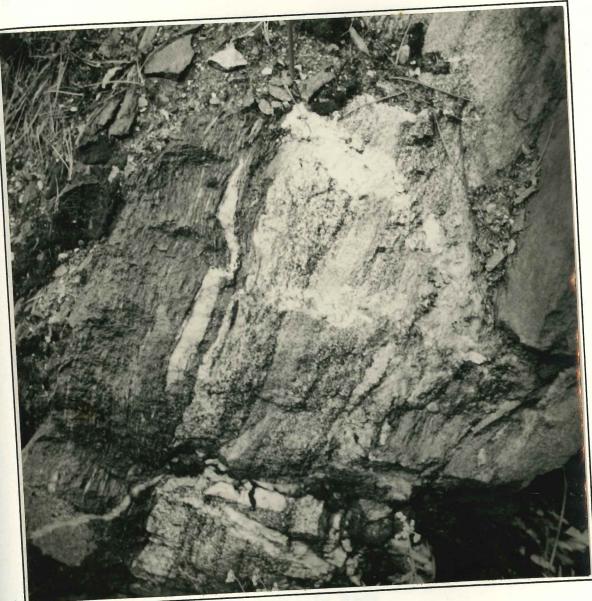
constant for mapped is shown in Flats B, but those rocks probably extend for beyond this area. When looking south from the algorist swamits near Stevens facal it appears that these grandless of the grandless of the st. It is rocked are continued to the north the grandless of the st. It is not the grandless of the st. It is not less to the lower, southern slopes of disolar Foak (Figure 1 and Flats III). From Stevens feas these grantles rocks extend for at less is allow to the west.

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The inches contacts of the granists recks with the scales and the scales recks of the scales recks of the scales and the scales and the scales and the scales and the scales of scales and scales and scales of the scales of the one hand and a relatively uniform granitic rook on the other (Flate IXXIV). Some of these wigned of alternating layers of its structure, being composed of alternating layers of homefaltied scales and granitic and scales and scales of the scales and structure, being composed of alternating layers of homefaltied scales, the granitic screet the schiefs and granitic screet the schiefs

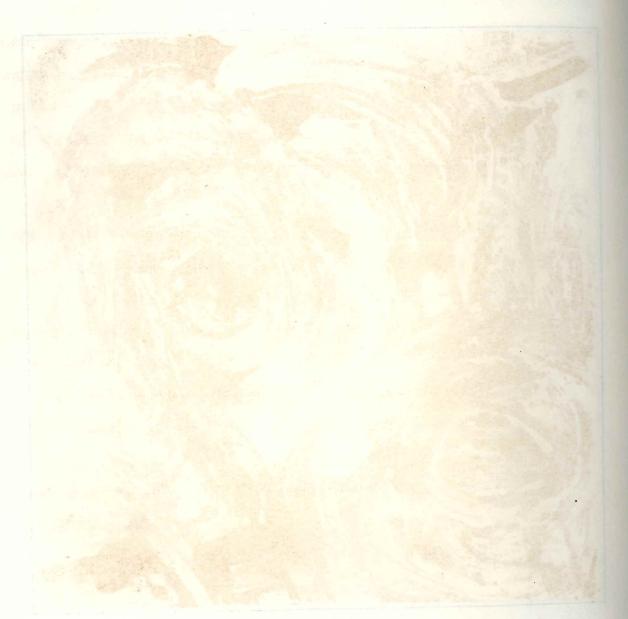
PLATE XXIV



6 inches

Migmatite zone. Relict foliation preserved in granitoid rocks by layers differing in content of mafic minerals. Later cross-cutting replacement veins and dikes contain microcline, plagioclase, and quartz. Lake Valhalla.





in dike-like, irregular bodies up to 50 feet in width. Such bodies contain numerous irregularly-shaped, haphazardlyoriented fragments of schist material which appear to indicate that brecciation of the schists has facilitated the emplacement of the granitic materials (Plate XXV). Excellent examples of this type of contact can readily be seen along the highway in the road cuts above and below the confluence of Mill and Nason

The second type of contact is restricted to the ridge Creeks. just south of the main summit of Mt. Fernow (Plate A). This contact is moderately to absolutely sharp and discordant (Plate XXVI). Here, also, the granitic rocks adjacent to the schists are filled with inclusions of the schists in varying stages of transformation, and the marginal several hundred yards of the granitic rocks can be considered a migmatite

The rocks of the main granitic body will be described zone. first, and those of their comparatively narrow migmatitic border zones later.

Description of the Main Granitic Body

The granitic rocks vary considerably in appearance and, to a lesser extent, in composition. Some are dark, bluish-grey, medium-grained, dioritic-like rocks dominantly composed of plagioclase, hornblende, and biotite. These

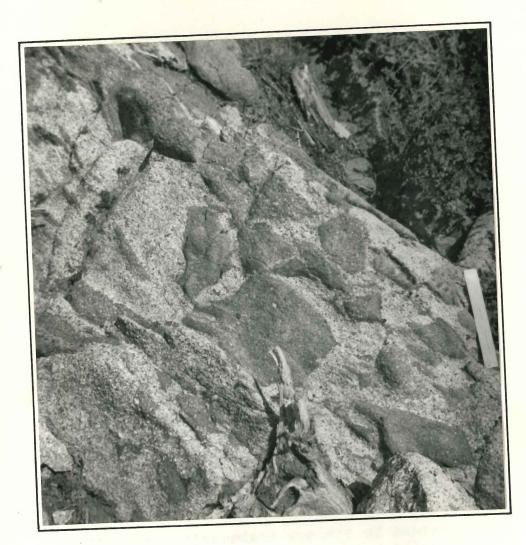
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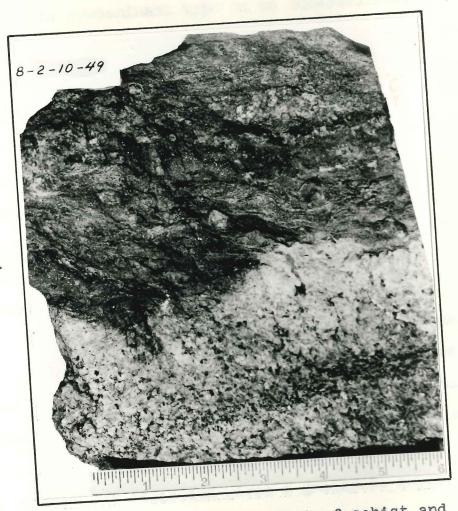
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PLATE XXV



Migmatite zone. Partial granitization of brecciated schists. Inclusions of schist material display varying degrees of felspathization and transformation. Southeast spur of Union Peak.

TATE XXVI



Sharp and discordant contact of schist and granitoid rock. Schists with a slight superimposed hornfelsic texture. South ridge of Mt. Fernow.

schists. Inclusions of schiet daterial varying degrees of felspechicaclon and Southeast apur of Union Peak.

dioritic rocks are usually restricted to the relatively narrow migmatitic zones on the borders of the main granitic body.

Other rocks, quantitatively unimportant, are very light in color, with plagioclase and quartz dominant, and few mafics present. The predominant type is an intermediate, leucocratic rock which is medium-grained and composed chiefly of plagioclase and quartz with biotite and hornblende in small, unevenly-distributed patches (Plate XXVII, A).

Structures and Inclusions. These dominant granitic rocks have apparently been considered as structureless and homogeneous by Smith (13,p.157). Inasmuch as most of them lack any preferred orientation of the mineral components, this is true. However, in many other ways they are far from being structureless and homogeneous.

Relict foliation is often found in these granitic rocks. Usually it is not associated with a preferred orientation of minerals but is displayed by varying proportions of dark and light minerals in alternating layers and elongated lenticles (Plate XXVII, B). There are numerous small areas where such relict foliation gives a gneissose appearance to the granitic rocks (Plates XXVII, B, and XXVIII, A and B). In the area southwest of Lake Valhalla, on the southeast spur of Union Peak above Smith Brook, and on Barrier Peak there are extensive northwest-southeast elongate areas, ranging from several hundred yards to over a mile in length, in which this

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depitte rocks are usually rectricted to the relatively narrow in the sold to end to the sold grantite body.

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PLATE XXVII



A. Leucocratic, medium-grained quartz dioritic rock. Patchy arrangement of mafic minerals. Near confluence of Mill and Nason Creeks (spec.

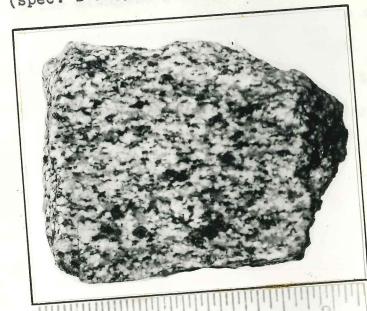


B. Gneissose quartz diorite. Relict foliation marked by darker and lighter bands.
Lake Valhalla (spec. B-2).

PLATE XXVIII



A. Quartz diorite. Variation between a directionless rock and one with relict foliation marked by layers of mafic minerals. East ridge of Barrier Peak (spec. 1-16-9-49).



B. Quartz diorite gneiss. Relict foliation marked by subparallel orientation of biotite and horn-blende. Summit of Barrier Peak (spec. 2-9-9-49).

Gneissose quartz diorite. Relighter fariation marked by darker and lighter bands.

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B. Quartz diurite gneiss. Relice foliation agried by subpareases crientation of biosite and normal blende. Summit of Barrier Jack blende.

relict foliation prevails (Plate B). In such areas the rock can be called a gneissose granitic rock. In all cases the attitudes of the relict foliation are parallel to those of the schists bordering the granitic rocks on the east.

In addition to the relict foliation, dark inclusions in varying states of transformation are frequently found.

Nowhere can a mass of granitic rock more than a few feet across be found that lacks these inclusions (Plate XXIX, A). The materials forming most of the inclusions vary from slightly hornfelsized schists to shadowy remnants or skialiths. There also are occasional inclusions of lenticular quartz masses, up to several inches in length, which are identical in shape and composition to the elongate quartz bodies so common in the biotite-quartz schists. These quartz inclusions contain elongate biotite plates in parallel orientation. Another type of inclusion which is fairly common, especially in the vicinity of Lake Valhalla, consists of lenticular aggregates or attenuated stringers composed of at least 95 per cent biotite. These vary in length from one inch to several feet.

Most of the various types of elongate inclusions occur singly or in small groups. When found in groups they display a striking parallel arrangement (Plate XXIX, B), and their orientation was found to be parallel to the attitudes of the orientation was found to be parallel to the attitudes of the schists and gneisses on the east, even where the inclusions schists and gneisses on the east, even where the contact of measured are as much as five miles distant from the contact of

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PLATE XXIX



A. Leucocratic quartz dioritic rock with inclusion of horn-felsized and felspathized schist material. Southwest of Lake Valhalla (spec. B-3).

PLATE XXIX (continued)



B. Quartz diorite. Elongate inclusions of hornfelsized schist material in parallel arrangement. Attitudes identical to those of adjacent schists. Southwest of Lake Valhalla.

Leucospanic quartz utorisis nock with inclusion of their felsized and felspann tel felsized and felspann tel schist material. Southwest schist material (spec. Br.)

the granitic rocks and the schists. At places the inclusions are not elongate in shape, and they show a random orientation and signs of rotation (Plate XXV). Such zones of inclusions are interpreted as schist areas which had become brecciated and subsequently were invaded by granitic materials.

The many inclusions of schists found within these granitic rocks vary considerably in texture and degree of transformation into more granitic rocks. Some of them are composed of schist which is unaltered except for a superimposed slight hornfelsic texture. Others are mere shadowy relics or skialiths which differ only slightly in texture and composition from the enclosing granitic rocks. In most cases the contact between the inclusion and enclosing granitic rock is transitional (Plate XXIX, A). Where the contact is sharp (and this is quite uncommon) there is usually a 0.5 to 2.0 mm wide selvage of biotite around the inclusion.

Many of the only slightly altered inclusions of schist have the following approximate composition: 25 per cent biotite, 25 per cent actinolitic hornblende or green hornblende, 25 per cent plagioclase, 10 per cent quartz, and accessories. Megascopically this type of inclusion often appears schistose, consisting of alternating lighter and darker bands. Microscopic examination shows, however, that the biotite and hornblende have predominantly lost their elongate shape and

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Regular jointing is very common in the granitic rocks.

Normally there are three sets of joints, roughly at right angles to each other, but apparently without a consistent orientation throughout the area.

Petrography. The bulk of the rocks forming the main granitic body are medium-grained and leucocratic with a completely crystalloblastic texture. All mineral constituents are anhedral, very irregular in outline, and interlock one with another. The dominant minerals are plagioclase, quartz,

costr parallol orientation due to a asperimposed static edt to eretette kind original structure of the delibered to much and at other a as olding tilde at daines I bends of graphite running through the maile orystals. Some of smos base, elegated elegated and normblande have remained elegate, and some mood even eletines theselps to each of intitle ears feron for prespried of relies. Usually there is syldence that hermblends moisesificate bytemeste that that the biolisication sad anciauted. Part of the plagiociase of the inclusions has gathquerrus saw lo sealoolgang and as nollisogres once sar To dank but to of a much smaller grain size. Mart of easts then the planiceless of the adjecent granitic material. Rosessory minerals, such as apatico, aphene, magnetite, and ranitic rock.

Acquiar jointing is very common in the granitic rocks.

Morgally there are three acts of joints, roughly at right:

Morgally there are three acts of joints, roughly at right:

Suggles to each other, but apparently without a consistent

offendation throughout the area.

Petrography. The balk of the rocks forming the main petrography. The balk of the rocks forming the main graphtic body are median-grained and leucocratic with a commit plately organizatio texture. All mineral constituents are unhoded, very irregular in outline, and interlock one much enchaer. The dominant minerals are plagicolase, quarter,

biotite, and hornblende, with subordinate migrocline. Apatite, sphene, orthite, magnetite, and occasional garnet are accessories, and epidote, clinozoisite, muscovite, and sericite have formed through secondary processes.

Plagioclase usually forms 50 to 60 per cent of the rock. The plagioclase crystals vary in size from minute, 0.1 to 0.2 mm rounded grains, to a maximum of 4.0 mm. The average to 0.2 mm in size. The plagioclase is generally twinned after is 2.0 mm in size. The plagioclase is generally twinned after the albite and carlsbad laws, though pericline twinning is the albite and carlsbad laws, though pericline twinning is also found. Complex zoning may occur in some of the larger also found. The average composition of the plagioclase is about crystals. The average composition of the plagioclase is about Ab70, with variations from Ab60 to Ab75.

Strain shadows are common in the plagioclase, and the crystals are often bent, frequently in an undulating fashion. Examples of fracturing of plagioclase grains and of healing by plagioclase substance are often found. Most of the plagioclase plagioclase substance are often found. Most of the plagioclase crystals contain numerous inclusions of biotite, hornblende, and quartz (Plate XXX, A). Retrogressive sericite, epidote, and clinozoisite may also be present in the plagioclase. The sericite has clouded many of the crystal centers and obliterated the twinning. Only the smaller plagioclase crystals which have formed in the intergranular spaces are clear. Frequently plagioclase has penetrated biotite and hornblende grains along their cleavage planes. Some plagioclase grains have pushed aside and bent out larger elongate grains of

protect and hornblends, with subordinate storcoline. Apatite, appears, orthite, especific, and occasional garnet are accesnories, and epidote, elimozoisite, succevite, and cericite

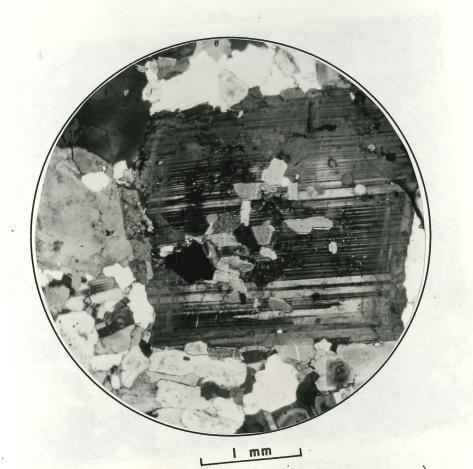
Plagioslass usually forms 50 to 50 per dent of the room. The plagioslass drystals vary in size from minute, 0.1 to 0.2 mm rounded grains, to a maximum of 4.0 mm. The average is constaily swinned after the slates and carisbad laws, though periodine twinning is also found. Complex sening may occur in some of the larger organis. The average composition of the pingiociase is shout the organis. The average composition of the pingiociase is shout organis. The average composition of the pingiociase is shout the organism than Abso to Abys.

Strain shedows are common in the plagiculase, and the empirical are often bent, frequently in an undulating feshion.

Install are often bent, frequently in an undulating feshion.

Plagiculase substance are often found. Most of the plagiculase anystele contain numerous inclusions of biotics, normblenie, and curres (Flate MIX, A). Actrogrammive serioite, apidote, and climotolaive may also be present in the plagiculase. The serioise has clouded many of the crystal centers and obliter—act the awdining. Only the smaller plagiculase crystals and have formed in the interprending spaces are clear. Frequently playiculase has pensurated blotte and horntlender have pushed saids and hent out larger elongate grains of have pushed saids and hent out larger elongate grains of have pushed saids and hent out larger elongate grains of

PLATE XXX



A. (Photomicrograph, crossed nichols)
Oligoclase porphyroblast. Incluoligoclase porphyroblast, chlorite,
sions of biotite, epidote, chlorite,
and quartz. Lake Valhalla (spec.
B-2).

PLATE XXX (continued)

B. (Photomicrograph, crossed nichols) Sodic oligoclase porphyroblast growing in ground-oligoclase porphyroblast growing in ground-mass of biotite, muscovite, and quartz. mass of biotite, muscovite oligoclase Inclusion of twinned calcic oligoclase (top). Quartz diorite. Lake Valhalla (spec. B-2).

XXX EINIV

Photomicrograph, crossed Midistry)
Phycolase perpuyroulast. 161 er
Mions of bistive, epidote, of artist
and quarts. inte Valhails (appea-

biotite and hornblende. Where hornblende is a major constituent the plagioclase is somewhat more calcic in composition. The same applies to rocks which originally possessed a high hornblende content but in which the hornblende has been extensively biotitized. More sodic plagioclase is found where biotite was the original mafic, or where a later stage of plagioclase growth has occurred (Plate XXX, B). Some of the larger plagioclase crystals show cloudy, more calcic centers with more sodic rims.

Quartz generally forms about 10 per cent of the rock, and exceptionally rises to 25 per cent. Like the plagioclase, the quartz occurs in irregular grains with crenulated borders characteristic of crystalloblastic growth. Several generations of quartz appear to be present. One generation apparently predates the plagioclase inasmuch as it is replaced and often engulfed by the plagioclase. To the same first generation are assigned occasional lenticular areas of a fine-grained quartz mosaic, up to one centimeter in length, which enclose elongated flakes of biotite in parallel orientation. These quartz patches bear a striking resemblance to the fine-grained, quartz-rich bands and lenticles commonly found in the biotitequartz and biotite-hornblende-quartz schists.

An intermediate generation of quartz appears to be contemporaneous with the growth of the bulk of the plagioclase. In several instances the outlines of small, subrounded quartz

storice and hornblende.

egge which originally possessed a high hornblende content but the midh the hornolande has been extensively biotitised. More sedie starfogiase is found where biotice was the original week eric, or mere a later stage of plagioclase growth his had executed by the plantociane. To the same first generation are setting beatern-ent's to asers refronteed landressoo bengines bedegnois sections dethy , dignet in tengines one of our office.

An intermediate generation of quartz appears to be contemporeneous with the growth of the bulk of the plagioclase.

grains of the quartz mosaics (cf., above) occur as relics
within a later-formed, larger quartz crystal of markedly difwithin a later-formed, larger quartz crystal of markedly different orientation. In addition, many of the biotite and
hornblende crystals penetrated by the plagioclase are also
invaded by quartz lying adjacent to the plagioclase. This
invaded by quartz lying adjacent to the plagioclase. This
intermediate generation of quartz is very conspicuous in those
intermediate generation of quartz is very conspicuous in quartz
hornblende-rich rocks which were originally very low in quartz
(cf., pages 34 and 35).

The latest generation of quartz fills minute fractures, up to 4 mm in width, which transect the rock, and this quartz is invariably associated with a vermicular growth of quartz and feldspar to be described below. In some cases this quartz appears to have grown into and to have wedged apart quartz appears to have grown into and to have wedged apart large crystals of plagioclase.

A vermicular growth of quartz and feldspar is often found in maggot-like patches along narrow, elongate zones.

Adjacent to these zones are quartz and plagioclase crystals and mortar structure. Showing strain shadows, snipped-off ends, and mortar structure. This suggests that the vermicular growth has taken place during a process of recrystallization occurring in minute fracture a process of recrystallization occurring in minute fracture. Usually these zones do not exceed 2 mm in width, though a maximum of 4 mm is exceptionally attained.

As in the case of the gneisses farther to the east (cf., page 51) this vermicular growth of quartz and plagioclase always occurs adjacent to microcline which encroaches upon and

erains of the querts mosaics (ef., above) occur as raites

into a later-formed, larger quarts crystal of markedly different orientation. In addition, many of the biotite and
localisate ergerals penetrated by the plagicolase are also
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intermediate generation of quartz is very conspicuous in those
intermediate-rich rocks which were originally very low in quarts

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quartz and feldaper to be described below. In some cases this
quartz appears to have grown into and to have wedged apart

A versicular growth of quarts and feldspar is often found in maggot-like patenes along narrow, elongate somes.

**Sound in maggot-like patenes are quarts and plagioclass drystais adjacent to these somes are quarts and plagioclass drystais choulng strain shadows, smipped-off ends, and sorter stracture.

**Contain suggests that the versicular growth has taken place during scotes of recrystallization occurring in minute fracture in somes. Usually these tones do not exceed 2 mm in width, though cons. Usually these tones do not exceed 2 mm in width, though const.

As in the case of the gnetases farther to the case (of., page 51) this vermioular growth of quarts and plagioclass class boots adjacent to microclise unich enerosches upon and

often engulfs pre-existing plagioclase and quartz grains.

Some of these microcline crystals may attain a size of 4 mm,

but less than half of this is the rule. In a few cases microbut less than half of this is the rule. In a few cases microbut less than half of this is the rule. In a few cases microbut less than half of this is the rule of the rock and then equals

cline forms as much as 10 per cent of the rock and then equals

quartz as a major constituent; but a microcline content of 5

quartz as a major constituent; but a microcline content of 5

In these recrystallized minute fracture zones the newly-formed, usually small plagioclase grains are more sodic than the plagioclase of the main rock. Their usual composition than the plagioclase of the main rock. Their usual composition is Ab75. The recrystallized quartz in such zones grows into the larger, earlier plagioclase crystals bordering these fractures.

This growth of microcline and quartz, in addition to plagioclase, implies that potassium and silica were introduced during the recrystallization of these late fracture zones.

Mafics compose up to 20 per cent of the rock. They are rarely evenly-distributed in the rock but generally form irregularly-shaped and irregularly-distributed clusters irregularly-shaped and XXVIII, A and B).

Biotite is usually dominant and forms irregular plates averaging 1 to 2 mm in size. In the biotite there is a strong averaging 1 to 2 mm in size. In the biotite there is a strong development of pleochroic haloes around zircon nuclei which development of pleochroic haloes around zircon nuclei which recalls similar phenomena in the schists. Small magnetite recalls similar phenomena in the biotite. The biotite grains are frequent inclusions in the biotite. The biotite crystals are often bent and gently folded and some show minute

of ten engulfs pre-existing plagioclass and quarts grains.

Sole of these misrocline crystals way attain a size of 4 mm.

But less than half of this is the rule. In a few cases wiero
aling forms as much as 10 per cent of the rock and then equals

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in these recrystallized minute fracture zones the newly-idended, usually small playloolsse grains are more sodic non the playloolsse of the main root. Their usual composition is now. The recrystallized quartz in such somes grows into the larger, earlier playloolsse crystals bordering these the

This growth of microcilne and quarter thursduped particular vere introduced particular toolage, implies that potage is a late fracture genes.

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Halics compose up to 20 per dent of the rock. They halics compose up to 20 per dent of the rock but generally form the ranely evenly distributed in the rock but generally form

District is usually dominant and forms irregular plates of usually dominant and forms irregular plates of usually dominant and forms irregular plates are not pleased along a record and a record and a record a r

fractures, some of which have only partially been healed.

Chloritization of the biotite along its cleavage planes is common, especially in more weathered specimens, and muscovite and sericite are additional products of the alteration of biotite.

The other mafic of major importance is either actinolitic hornblende or, less frequently, common green hornblende. The actinolitic hornblende is identical with that previously described from the schists, and its quantity occasionally exceeds that of the biotite in the granitic rock. The hornblende occurs in irregular grains up to 5 mm in size, although most crystals do not exceed 2 mm. It is usually more or less biotitized, and in a few examples biotitization has almost eliminated hornblende from the rock. Most of the biotite is obviously derived from the hornblende. Small, rounded grains of magnetite associated with and often included in the biotite are interpreted as having formed during the biotitization of hornblende to accommodate some of the released iron. This biotitization of the hornblende indicates that an introduction of potassium occurred at an earlier stage than the more local, late introduction which caused microcline to form (cf., pages 75 and 76).

It has been emphasized that the mafics in these granitic rocks commonly form unevenly-distributed irregular clusters. In most cases these patches lack preferred orientation. Proctures, some of maight have only partially been needed.

Chioristration of the biotite along its aleavage planes is

domain, especially in more weathered specimens, and muscovite
and ceriotic are additional products of the alteration of

-onlype maile at someground rotem to other reduce out iste hermbiende or, less frequently, common green hormblende. at edited hornblande from the rock. Most of the biguite in obviously deprived from the hormblende. Small, rounded grains northerent as and selection of the hornor but to northerestiliate of potentium occurred at an earlier stage than the more local, late introduction which caused microcline to form (cf., pares

It has been suphasized that one mailes in these granlife rooms demanaly form unevenly-distributed irregular clusHowever, at some places a parallel orientation of the mafics does occur (Plates XXVII, B, and XXVIII, A and B). Many rocks, megascopically directionless, contain gently curved polygonal arcs of biotite and hornblende. In addition, there are large areas, such as the ridge of Barrier Peak (Plate A), where an alternation of lighter and darker bands varying in their proportion of mafics gives the rock a gneissose appearance. This structure is due to a compositional variation rather than a preferred orientation of the individual mineral constituents. It is noteworthy that on Barrier Peak, and in other similar areas, the gneissose structures have attitudes parallel not only to those of closely adjacent inclusions of hornfelsized schists but also to the trend of the main schist body lying east of the granitic rocks. Accessory minerals in the granitic rocks are orthite,

Accessory minerals in the grantout sphene, apatite, and occasional garnet. Epidote, clinozoisite, muscovite, and sericite are frequently found as secondisite, muscovite, and sericite are frequently found as secondary minerals in and around plagioclase and biotite. Part of
ary minerals in and around plagioclase and biotite. Part of
these secondary minerals probably are retrogressive and formed
these secondary minerals probably are retrogressive and formed
during a time of falling temperatures, and part may be the
there is a conspicuous similarity
result of weathering. There is a conspicuous similarity
between the accessory minerals of these granitic rocks and the
decessory minerals of the schists and gneisses previously
described (cf., pages 35, 49, and 50).

normal at some places a parallel erientation of the marica ness onder (Plates MVII, B, and MVIII, A and B). Many rooms, megasopiesily directionless, contain gently ourved . (A stell) Meet telred to egbir ad the there is a come of the and the come of micro an alternation of lighter and darker bands verying in their proportion of mailes gives the rock a gneissose appasrmolistrav isnolilacquos a co sub al armionia atar . sono rement than a preferred orientation of the individual mineral constituents. It is noteworthy that on Barrier Peak, and in parallol not only to those of closely sajacent inclusions of delide nism off to beet off of the trend of the main sobiet

cynome, apatite, and occasional garnet. Epidote, olinozo--Antic, cuscovite, and sericite are Trequently found as secondblace secondary winerals probably are retrograssive and formed during a time of falling temperatures, and part say be the result of weathering. There is a conspicuous similarity was described (of , pages 33, 49, and 50).

The bulk of the granitic rocks in this area can be called leucocratic quartz diorites. Quartz-poor varieties may be called quartz-bearing diorites. Local varieties in which microcline makes up as much as 10 per cent of the rock approach a trondhjemite in composition. the Europeta materials or spectrally posterior with the re-

Description of the Migmatitic Border Zones

The granitic rocks are everywhere in gradational contact with the schists, with the one exception of the ridge of Mt. Fernow (cf., page 60). However, regardless of the type of contact, the border zones of the granitic body display all variations between relatively uniform, mostly directionless granitic rocks and partly directional, partly directionless migmatites composed of schists and granitic rocks.

Proceeding from the main granitic body towards a contact with the schist, the inclusions, which in the main body usually form amounts of less than 2 per cent, become more and more abundant, and finally an area of dominant schist is reached. These mixed border zones vary from a hundred yards to as much as a mile in width. Since in these migmatitic zones there exist all gradations between and all proportions of granitic and schist material, it is impossible to single out one specimen or one small area as being typical. However, regardless of their position within the migmatite zones, the rocks in these zones do possess certain common characteristics. The bulk of the granttle rooms in this area can be called leucocratic quartz diorites. Quartz-poor varieties in as the called quartz-bearing diorites. Local varieties in which adoreoline makes up as much as 10 per cent of the room approach a troudhjemite in composition.

Econoriputon of the Higmatitte Surder Lones

Who granitic rocks are everywhere in gradational contest with the schiats, with the ene exception of the ridge of at fermow (ef., page 60). However, regardless of the type of contact, the border zones of the granitic body display all contact, the border zones of the granitic body display all veriations between relatively uniform, mostly directionless creater rocks and partly directional, partly directionless.

Proceeding from the main granitic mody communication to the main body used with the schiet, the inclusions, which in the main body negative form amounts of less than 2 per cent, become sore and more abundant, and finally an area of communication these mixed border zones vary from a nundred yards reached. These mixed border zones vary from a nundred yards to as much as a mile in width. Since in these mignativities constituted and schiet saturial, it is impossible to single out one specimen or one small area as being typical. Mowever, regardless of their position within the mignatite zones, the roots in these zones do possess certain dosmon characteristics.

- 1. The contacts between the relatively coarse-grained, leucocratic granitic rocks and the much more fine-grained, leucocratic granitic rocks and the much more fine-grained, darker schists are usually gradational. This applies, regardless of whether the schist is a small, blocky or rounded less of whether the schist is a small, blocky or rounded inclusion within the granitic rock, a layer intercalated in the granitic material, or spatially continuous with the main schist area.
- zones megascopically resembles the rocks found in the main, uniform schist area, it generally displays a superimposed uniform schist area, it generally displays a superimposed hornfelsic microtexture, especially so in schist inclusions which are surrounded by granitic material. Relict schistosity and occasional polygonal ares have, in the majority of cases, and occasional polygonal ares have, in the majority of cases, been preserved in the schist materials, but most of the mafics have recrystallized into irregularly-shaped and haphazardly-bave recrystallized into irregularly-shaped and haphazardly-oriented grains, some of which enclose thin bands of graphite oriented grains, some of which enclose thin bands of graphite inclusions of skialith-type.
 - 3. With the hornfelsic texture there is always associated a growth of small plagioclase grains, usually of a somewhat more sodic composition than the larger plagioclase crystals more sodic composition than the larger plagioclase crystals found in the adjacent granitic rocks. At the same time the found in the adjacent granitic rocks. At the same time the found of quartz has increased; this increment is particularly amount of quartz has increased; this increment is particularly conspicuous where the original rock was a quartz-poor

the contests between the relatively coarse-grained, -braner . religie eldi . isnolusberg vilamen era bichnes romani ni bodalaovodni vajai a . Moor oldinava, and militar moleculari

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hornblende schist or amphibolite. During this metasomatic plagioclase and quartz growth, elongate biotite and hornblende crystals were included along the twinning planes of plagioclase and were invaded and engulfed by plagioclase and, less fre-

The superimposed hornfelsic texture, and the increase quently, quartz. in plagioclase and quartz observed in the schist material within the migmatite zone, gradually disappear with increasing distance from the contact between migmatite and schist. A few hundred yards from the contact the schists usually possess a well-marked orientation of their mafic constituents.

- 4. The granitic rocks of the migmatite zones vary in composition and texture. The specific variety of granitic rock produced appears to depend upon the variety of schist which was invaded, and upon the degree of felspathization and transformation of this schist material. Where biotite-quartz or biotite-hornblende-quartz schists have been transformed into granitic rock, a leucocratic quartz dioritic rock has resulted. Where an amphibolite was the country rock, a dark dioritic rock has been formed (Plate XXXI). The latter variety is especially common along Nason Creek where schists rich in actinolitic hornblende and common green hornblende have been infiltrated by granitic materials (Plate XXXII).
 - 5. One fact concerning the migmatite zones must be emphasized. With but one exception (cf., page 60) there is no

platicularde sonier or amphibulity. During this metarometro
platiculars and quarts growth, storighte bickite and normalenie
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Interpretation of the state of the senter action and senter material with the signative such as senter and senter a few distance from the contact between mignative and senter. A few mandred, and from the contact the senters usually pouseds a medit-marked orientation of their marke constituents.

position and texture. The specific variety of grantite rock position and texture. The specific variety of grantite rock produced appears to depend apon the variety of sonist which wan inveded, and upon the degree of frispathization and transformation of this sonist material. Maers bistite-quartz or bistite-normalism-quartz staimts have been transformed or bistite-normalism-quartz staimts have been transformed into grantite rock, a leasocratic quartz dioritic rock has resulted. Where an amphibolite was the doubtly rock, a dark dioritic rock has been formed (Flato XXXI). The latter variety dioritic rock has been formed along Mason Creuk where santate rich in detinated hormblends and common green hormblends have been antitrated by grantite materials (Flate XXXII).

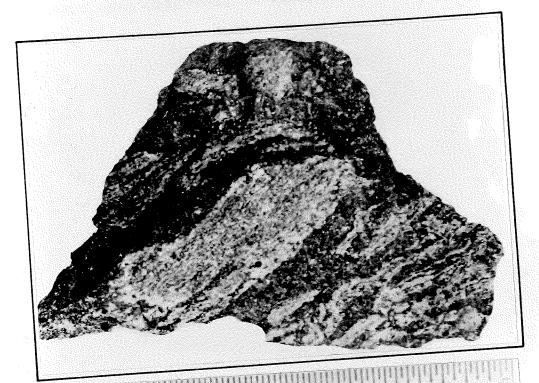
5. One fact concerning the eignatite conse must be caping

PLATE XXXI



Migmatite. Felspathized amphibolite. Textural and compositional variation from a dioritic rock and composition from

PLATE XXXII



Migmatite. Felspathization of an amphibolite along the planes of relict foliation. Road cut, one mile northwest of confluence of Mill and Nason Creeks (spec. 6-22-9-49).

evidence of forcible intrusion of the schists by granitic materials. There is no evidence of magmatic flow structure, regardless of whether the granitic material is intercalated in the schists or, as is more often the case, transects the schists in vein and dike-like irregular masses. No dilation effects have been observed. A static invasion of the schists by granitic materials is indicated by the many discontinuous but aligned layers of schist material lying within the granitic rocks, and the frequent folded relict structure marked by alternations of lighter and darker bands (Plate XXXIII).

Rotated schist blocks with random orientation are common, but the migmatite zones containing these rotated blocks are interpreted as being replacement breccias, and the rotation of their schist blocks is attributed to pre-granitic tectonic brecciation. This interpretation of replacement breccias formed by incomplete static granitization of previously brecciated schists is strongly suggested by the following features:

- a. There is no evidence of magmatic flow structure (cf., page 81).
- b. All textures in schist materials and granitie rocks are crystalloblastic.
- c. The migmatite zones contain many large, shadowy blocks with hornfelsized schist centers which show a complete gradation between a relatively coarse-grained granitic rock and a much finer-grained hornfelsized

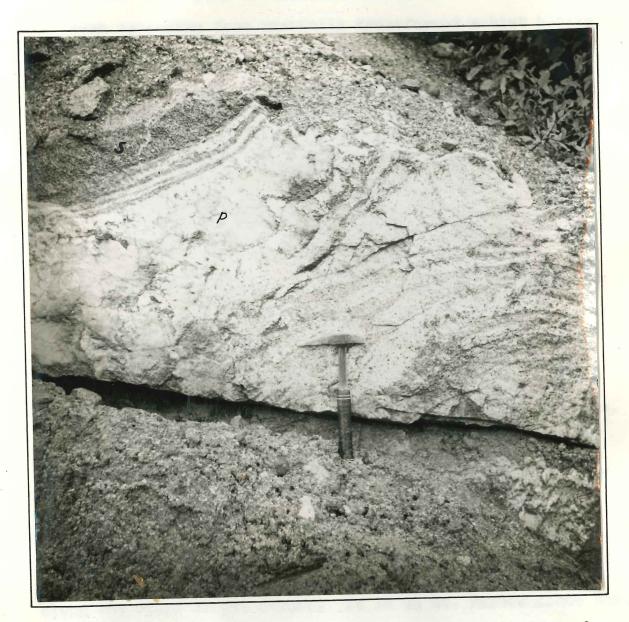
evidence of forcible intrusion of the schiets by granition enterists. There is no evidence of asgustic flow structures regardless of whether the granitic material is intercelated in the schiets or, as is note often the case, transocts the schiets in vein and dike-like irregular masses. No dilecton schiets have been observed. A static invasion of the schiets as granitid faterials in indicated by the many discontinuous but aligned layers of schiet material lying within the granitic recals, and the frequent folded reliat structure marked by seconds or lighter and darker bands (Flate XXIIII).

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e. The mignatite somes contain many large, shadows blocks with hornfelated schist centers which show a complete gradation between a relatively coarse-grained presided cock and a much liner-grained hornfelaised.

PLATE XXXIII



Migmatite zone. Relict folds preserved in granitoid rock by alternations of darker and lighter bands. Layer of hornfelsized and felspathized schist material (s). Postgranitic quartz and feldspar pegmatite (p). North slope of Mt. Fernow.

schist (Plate XXXIV).

d. Stringers of mafic materials can be frequently seen extending from partially transformed schist blocks into the granitic rocks, and sometimes these stringers extend completely across the dike-like granitic bodies.

Genetic Interpretation

The field and petrographic evidence presented is interpreted as indicating that the bulk of the granitoid rocks found in the Stevens Pass area have been formed by the metasomatism of pre-existing schists and amphibolitic rocks. It has been pointed out above (cf., pages 75, 77, 81) that there is evidence for an introduction of sodium, potassium, and silica which caused the isochemically-metamorphosed rocks, most of which contained hornblende, to be changed in texture, structure, and composition to predominantly quartz dioritic granular rocks (cf., pages 51-53 for a detailed discussion of similar metasomatic processes).

This conclusion applies to the entire granitic area thus far mapped, except for the granitoid rocks occurring along the ridge of Mt. Fernow. It is on Mt. Fernow alone that a sharp and discordant contact of schist and granitoid rock was found. Here also occurs an abrupt change in the prevailing strike of the schists (Plate B) which, coupled with the sharp contact, may indicate that at this locality the granitic rocks

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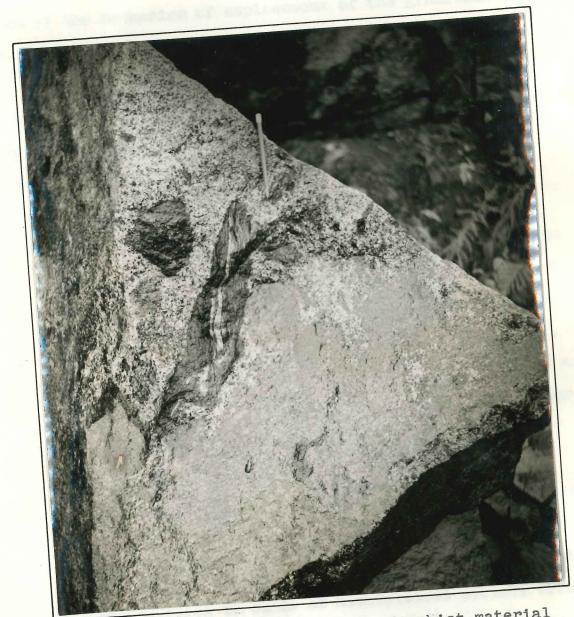
d. Stringers of materials can be frequently teams of med somist blooms are extending from partially teamsformed somist blooms are transfers the grantite seed sometimes the cantile bodies.

General Interpretation

The field and petrographic tyidence procented is interpreted as indicating that the bulk of the granitoid rocks found in the Stevens Pass area mays been formed by the wetademotian of pre-existing schists and amphibolitic rocks. It is been pointed out above (of., pages 75, 77, dl) that there is evidence for an introduction of socium, potassium, and silies which caused the isoensmically-metamorphosed rocks, atlies which contained hornblende, to be enanged in texture; structure, and composition to predominantly quarts dioritic granular rocks (of., pages 51-53 for a detailed discussion of granular rocks (of., pages 51-53 for a detailed discussion of

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PLATE XXXIV



Replacement breccia. Inclusions of schist material vary in degree of transformation from hornfelsized biotite-quartz schist to skialiths. Dark inclusion to the left of the biotite-quartz schist is a segretation of mafic minerals. Lower Mill Creek.

have forcibly intruded the schists. However, further field and petrographic study is necessary before a valid interpretation of the mechanism of emplacement of the granitoid rocks of Mt. Fernow can be made.

In all other areas there is evidence for a metasomatic origin of the granitic rocks. This evidence has been presented above in the descriptions of the rocks and may be summarized as follows:

1. Field evidence:

- a. The contacts between granitic rocks and schists are extremely gradational and are accompanied by wide migmatitic zones in which all kinds of transitions between schists, various types of gneissose rocks, and directionless granitic rocks occur (cf., pages 58 and 79). Similar transitions are found in the interior portions of the granitic body where inclusions and relict bands of schist occur.
- b. Many of the schist inclusions found in the interior parts of the granitic body, often miles from the migmatitic border zones (cf., page 66), are aligned and are parallel to bands of hornfelsized schists within the granitic body. Both schist inclusions and bands are parallel to the strike and dip of the schist adjacent to the granitic body. The lack of disturbance of these relict schist inclusions and layers appears to

have foreibly introded the simiste. However, further field to exect biotiners end to demonstant of the granitoid rocks of . We. Farmow can be made.

In all other areas there is evidence for a metanomatic origin of the granitic rooks. This evidence has been presented above in the descriptions of the recks and may be sweets ted as follows:

d. Freid evidence:

the grandtie body. Both schist inclusions and bands and to the granitio body. The lack of disturbance of

preclude emplacement of the granitic body by forceful injection of the country rock.

- c. Relict foliation occurs, both in the migmatitic border zones and in the interior portions of the granitic body. It is parallel to the strike of the schist adjacent to the granitic body (cf., pages 66, 78, and 86).
- d. Neither in the migmatitic border zones, nor where schist material occurs in the interior of the granitic body, were any structures seen which would indicate forcible intrusion or dilation (cf., page 81). 2. Petrographic evidence:

- a. The textures of the various granitoid rock types are entirely crystalloblastic (cf., page 70, etc.). The growth of plagioclase and quartz, at the expense of and around pre-existing minerals, is especially conspicuous, suggesting replacement.
- b. The granitoid rocks conspicuously lack a uniform composition, chemically, structurally, or texturally (cf., pages 63, 75, 77, and 81). Layers and inclusions of schist material, and unevenly-distributed patches of mafic minerals, emphasize this heterogeneity.
- c. The type of granitoid rock is apparently determined by the type of schist replaced. There is a definite association of dioritic types with hornblende-rich

preclude emplacement of the grenitic body by forceful injection of the country rock.

- e. Reliet foliation occurs, both in the migmatitic border romes and in the interior portions of the granistic body. It is parallel so the strike of the source adjacent to the granitic body (of , pages 56, 76, and 86).
- d. Meither in the migmatitic border zones, nor where senist material occurs in the interior of the granitic body, were any structures seen which would indicate foreible intructon or dilation (cf., page 81).
 - Patrographic evidence:
- are entirely crystalloblastic (cf., page 70, etc.).
 The growth of platicoless and quarts, at the exponse of and around pre-existing minerals, is especially consultations. Suggesting replacement.
- b. The granically conspicuous; seek a unitary composition, chemically, structurally, or texturally (cf., pages 63, 75, 77, and 31). Layers and inclusions of schiol material, and unevenly-distributed paterial or mafic minerals, emphasise this heterogeneity.
- c. The type of grantsold rook is apparently determined

schists, and of quartz dioritic types with biotitehornblende-quartz schists (cf., page 81).

- d. Relict schistosity and occasional polygonal arcs of biotite and hornblende are common to both hornfelsized schists and granitic rocks (cf., page 78).
- e. Both the relict inclusions and the surrounding granitic rocks have accessory minerals usually identical in quantity and type (cf., page 70).
- f. The mafic minerals of the relict schist material and the surrounding granitoid rocks are of identical composition (cf., page 77).
- g. The plagioclase of the hornfelsized schists and of the granitic rocks varies in a similar manner, being more calcic in the presence of hornblende, and more sodic in the presence of biotite as the original mafic mineral (cf., pages 74 and 81).

between the schist material and the granitic rocks is an addition of sodium and silica and minor potassium to the granitic rock which has led to an increase in plagioclase and quartz, to the biotitization of part of the hornblende, and to a more local development of late microcline.

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of biotite and normblende are common to both hormfelsized rehists and granitic rocks (cf., page 78).

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wore adde in the presence of biorite as the original maffe, mineral (of., pages 74 and 81).

From a chemical point of view, the essential difference between the schiat material and the granitic rocks is an addition of sodium and silica and minor potarsium to the granitic rock and quarts.

to the bibtitization of part of the normblende, and to a more

local development of late microcline.

being more calcie in the presence of hornblende, and

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